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Evaluation of Spacecraft Technology Programs (Effects on Communication Satellite Business Ventures)—Volume I

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SUMMARY

Commercial organizations as well as government agencies invest in spacecraft (S/C) technology programs that are aimed at increasing the performance of communications satellites. The value of these programs must be measured in terms of their impacts on the financial performance of the business ventures that may ultimately utilize the communications satellites. An economic evaluation and planning capability has been developed and used to assess the impact of NASA on-orbit propulsion and space power programs on typical fixed satellite service (FSS) and direct broadcast service (DBS) communications satellite business ventures. The developed methodology is based upon a stochastic financial simulation model (i.e., DOMSAT II) that allows for the explicit and quantitative consideration of reliability and various market, performance and cost uncertainties. The Model developes financial performance measures, including quantitative risk measures, that allow the impacts of the technology programs to be determined.

Typical FSS and DBS spin and three-axis stabilized spacecraft were configured in the absence of NASA technology programs. These spacecraft were reconfigured taking into account the anticipated results of NASA specified on-orbit and space power programs. Nonrecurring and unit recurring costs were estimated (using the PRICE cost model) for all of the spacecraft configurations and financial analyses performed of FSS and DBS business ventures utilizing these spacecraft. In general, the NASA technology programs resulted in spacecraft with increased capability — this was taken into account in the analysis.

This report describes the developed methodology for assessing the value of spacecraft technology programs in terms of their impact on the financial performance of communications satellite business ventures. Results of the assessment of NASA specified on-orbit and space power technology programs are presented for typical FSS and DBS business ventures. These results are extrapolated to indicate the potential market for the developed technology and the possible implications of the programs on spacecraft imports and exports.

This report consists of two volumes. Volume 1 describes the methodology and contains the results of the analyses performed for the on-orbit propulsion and space power technology programs. Volume 2 contains appendices describing the DOMSAT II Model and data base and includes user and programmer documentation.

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This work was performed under the guidance of Mr. Karl Faymon, NASA Lewis Research Center. The NASA Lewis Research Center technical staff provided valuable assistance with respect to the considered technology programs. Numerous commercial organizations including RCA Americom, Fairchild, Comsat, Direct Broadcasting Satellite Corp. and GT&E provided valuable information with respect to the structuring of the business scenarios that were considered in the analysis.

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0. SUMMARY/CONCLUSIONS/RECOMMENDATIONS

0.1 Summary

An economic evaluation and planning capability was developed that is appropriate for the evaluation of spacecraft (S/C) technology programs (such as those associated with space power and on-orbit propulsion systems) in terms of their impacts on communications satellite business ventures. Technology assessments and projections were made and, using the developed capability, an assessment was made of the impact of NASA specified S/C technology programs on typical fixed satellite service (FSS) and direct broadcast service (DBS) communications satellite business ventures and to U.S. spacecraft markets. The impacts were assessed in terms of the changes in financial performance measures such as cash flow, present value of cash flow and return on investment that may result from the use of the new and/or improved S/C technology (i.e., ion-thruster on-orbit propulsion and Gallium Arsenide solar cells).

The establishment of the impacts of technology programs on communications satellite business ventures requires the formulation of typical communications satellite business ventures, the simulation modeling of these ventures, the establishment of appropriate business and technology data bases, and the analysis of the business ventures without and with NASA investment in S/C technology programs. The formulation of typical FSS and DBS business ventures included the specification of services to be provided and the demand for these services,

sparing arrangements, use of insurance, number of satellites and desired launch dates, space transportation scenarios, anticipated launch dates, financial data (i.e., cost, expense, and capital expenditure data) and S/C attributes without and with the NASA technology programs. Both spin and three-axis stabilized configurations were considered. The S/C configurations served as the basis for cost estimation using the RCA PRICE Model. The S/C configurations provided inputs to the financial analysis such as subsystem reliability and the consequences of failures, number of transponders, and recurring and nonrecurring costs. Cost, demand, timing and other areas of uncertainty were explicitly and quantitatively considered as were S/C subsystem and launch system reliabilities. As a result expected values were established for all financial performance measures as well as explicit and quantitative measures of risk.

To accomplish the financial analysis, the stochastic financial simulation model, DOMSAT II, was developed. This Model can represent a broad range of FSS, DBS and other communications satellite business ventures. The Model is specifically configured to assess the impacts of the S/C technology and related programs upon the financial performance of FSS and DBS business ventures. The DOMSAT II Model is implemented so as to operate on the IBM-PC (in FORTRAN) with input data provided via a user friendly LOTUS 123 system.

The analysis of a S/C technology program first requires the formulation of base case communications satellite business scenario utilizing a base case S/C configuration. S/C attributes

are used to derive nonrecurring and unit recurring cost and the S/C cost and performance attributes are specified to the DOMSAT II Model as are other characteristics of the business scenario. The Model then establishes the financial performance measures of the business as a function of time. The effect of S/C technology programs are assessed by specifying the anticipated results of the technology program, reconfiguring the S/C utilizing the assumed new level of technology, costing the S/C and specifying the cost and performance attributes to the DOMSAT II Model. New financial performance measures are then developed utilizing the new S/C in the specified business scenario, and these measures compared with the base case.

Changes in the financial performance measures resulting from the S/C technology programs were used as the basis for judgements concerning the likelihood of the results of ion-thruster and Gallium Arsenide solar cell programs being incorporated into spin and three-axis stabilized S/C used by typical FSS and DBS business ventures. These estimates were then extrapolated (with some degree of trepidation because of the limited number of scenarios considered) to the satellite markets and estimates made of the likely impacts of U.S. and foreign on-orbit and solar cell technology programs on the market for U.S. manufactured satellites.

The developed methodology, and in particular the DOMSAT II Model, may be used to evaluate a broad range of program and policy alternatives. In addition to the evaluation of S/C technology programs, the Model can be used to assess the impacts on communications satellite business ventures of:

* utilizing alternative space transportation systems (i.e., expendable vs. reusable).

* achieving improved payload placement accuracy.

* different insurance rates as compared with the self-insurance option explicitly taking into account the level of risk.

* transportation system technology programs (for example, low thrust from LEO to GEO; improved upper stage reliability; etc.).

* space transportation system pricing policies.

* pricing policies for transponders and related services.

* S/C configuration alternatives including sparing design, number of active transponders, and on-orbit life.

* regulatory programs.

The above program and policy impacts may be assessed in terms of specific business scenarios - i.e., at the micro level - and include explicit and quantitative measures of risk.

0.2 Conclusions

A number of conclusions may be drawn from the results of the previously described analyses. It must be cautioned that a number of these may be "weak" since they are based upon the results obtained from the analyses of a very limited number of business scenarios and S/C configurations.

It is concluded that:

* The developed methodology provides the means for assessing the impacts of S/C technology programs on communications satellite business ventures. It provides a quantitative means for establishing financial impacts that can be used to improve qualitative judgements with respect to the likelihood that the resulting technology will gain widespread acceptance.

* The use of ion-thrusters and Gallium Arsenide solar cells resulting from NASA technology programs have the potential of reducing the mass of FSS and DBS S/C. The mass reduction may be taken in the form of transportation cost savings (when transportation costs are in direct proportion to payload mass) or the mass may be replaced so as to increase S/C capability - i.e., increased reliability, increased S/C expected on-orbit life, increased number of active and/or spare transponders, etc.

* The desirability of and the specific manner in which mass savings should be replaced depends upon many factors including the demand for and price of transponders, subsystem reliability characteristics, transportation cost, and regulatory constraints (for example, maximum allowable power density on ground).

* The considered technology improvements lead to increased nonrecurring and unit recurring costs (relative to base case S/C). A portion of these increases is the result of increased S/C capability, refer to Table 1, but the major portion is due to the incorporation of the new technology.

TABLE 0.1 S/C COST AND CAPABILITY SUMMARY

SPACECRAFT	EXPECTED NONREC. COST (M$)	EXPECTED RECURRING COST (M$)	NO. OF ACTIVE TRANSP.	WEAROUT LIFE (YRS)
FSS				
BASE CASE	20.8	38.6	16	8
ION-THRUSTER	44.2	43.9	20	10
GA SOLAR CELL	31.0	38.8	18	8
DBS				
BASE CASE	39.9	66.9	3	7
ION-THRUSTER	75.8	77.2	4	9
GA SOLAR CELL	45.3	65.7	3	9

* The use of the new technology, in general, increases the profitability of the typical FSS and DBS business ventures in the long-term. This could not be achieved, without higher nonrecurring and unit recurring costs, with an accompanying increase in indebtedness (negative of cumulative cash flow) in the near-term. The net effect is an increase in the required investment in the near-term to achieve an increase in profits in the long-term. The magnitude of the increase in indebtedness is primarily due to the nonrecurring cost.

* Without reductions in the nonrecurring cost it is unlikely that the ion-thruster technology will find

quick acceptance - the effect of the increase in ROI and other financial performance measures is likely to be more than offset by the effect of increased required investment for using a technology that is perceived to be relatively high risk. This can be altered by reducing the nonrecurring cost and perceived risk by undertaking flight demonstration programs as part of the technology program.

* The improved solar cell technology is likely to find early acceptance because of the increase in financial performance measures which are not offset by significant increases in nonrecurring cost.

* Since both considered technology programs can offer significant benefits to communications satellite business ventures (and are likely to be utilized if the nonrecurring cost hurdle can be reduced), foreign technology developments are important. Since foreign technology programs similar to the ion-thruster and Gallium Arsenide solar cell technology programs of NASA are being conducted it may be concluded that without comparable U.S. programs, the foreign technology program results are likely to be incorporated into S/C design. This will undoubtedly give foreign S/C manufacturers an advantage over U.S. S/C manufacturers and may erode U.S. spacecraft markets.

0.3 Recommendations

A number of recommendations are indicated in the following paragraphs. These are organized under the general headings of Technology Programs, Analyses, and Model Improvements.

Technology Programs

* It is recommended that NASA S/C technology programs include efforts specifically aimed at reducing S/C non-recurring costs when the technology program (for example, the ion-thruster program for on-orbit propulsion) is likely to lead to a substantial increase in the nonrecurring cost of a S/C utilizing the NASA developed technology. This is particularly important since the benefits of the technology program will not be achieved unless the private sector utilizes the developed technology. Even though there are long term financial benefits as a result of the use of the technology, the near-term increase in indebtedness and risk may make it unattractive to utilize the technology.

* It is recommended that combinations of technology programs be analyzed (on-orbit propulsion and space power programs have been analyzed separately).

* It is recommended that the analysis be extended to encompass new spacecraft configurations.

* It is recommended that other S/C technology programs be evaluated in terms of their impacts on communications satellite business ventures. This will provide quantitative information that will be useful for formulating an overall S/C technology program.

* It is recommended that the use of the DOMSAT II Model be incorporated as standard procedure into the program planning and evaluation process.

Analyses

* It is recommended that other business scenarios and S/C configurations be considered. Only one FSS and one DBS business scenario in combination with a spin stabilized and a three-axis stabilized S/C, respectively, have been analyzed. To make the results more robust it is necessary to consider other business scenarios and S/C configurations.

* To fully appreciate the significance of the impacts of the technology programs on the financial performance measures and the resulting likely impacts on investment decisions, it is recommended that an assessment be made of the likelihood of investment decisions in terms of financial performance measures. The result would be a better appreciation of the likelihood that communications satellite business ventures will use the results of the NASA technology programs and the results that are necessary to achieve acceptance by the private sector.

* It is recommended that the analysis be extended to the area of mobile communications satellite business ventures. Since it may be more likely that mobile communications satellite business ventures will develop than DBS business ventures, future analyses should place more emphasis on mobile applications than on DBS applications.

Model Improvements

* It is recommended that the DOMSAT II Model be modified so as to include a set of cost estimating relationships as an integral part of the Model. This will reduce the complexities of the overall analysis of each technology program and will allow mass and power (and other attributes that may be variables in the cost estimating relationships) uncertainties to be considered and their impacts determined. Inputs to the Model would then

include estimates of subsystem mass and power and their uncertainties. Cost estimation would be performed by the DOMSAT II Model and not exogenously.

* It is recommended that the Model be modified so as to include other transportation scenarios such as repair, retrieval, and reusable upper stages. It is also recommended that the Model be modified to explicitly include the transportation scenarios that may result from the use of the Space Station as a transportation node. This will allow assessments to be made of the value of these other transportation scenarios and associated pricing policies on communications satellite business ventures.

* It is recommended that a number of minor modifications be made to the DOMSAT II Model to eliminate deficiencies that have been found during its use and application to the FSS and DBS analyses.

1. INTRODUCTION

The justification of R&D programs that lead to spacecraft technology improvements encompasses the establishment of the benefits in terms of improved scientific knowledge that may result from new and/or improved NASA science missions, improved cost effectiveness of NASA and DOD missions and new or improved services that may be offered by the private sector (such as communication satellite services). Cost effectiveness benefits associated with government programs may be established in terms of life cycle cost reductions in achieving a specified set of mission requirements. [1-4] Benefits that may result from government programs aimed at the development of technology that might alter commercial business venture investment decisions and profit and cash flow patterns can only be evaluated by planning and evaluating business ventures that might be impacted by the technology developments. [5-7] Attention has focused on this latter area.

Analyses have been performed that lead to the establishment of the financial impact of spacecraft technology improvements on private sector communications satellite business ventures. This is accomplished by assessing the value of spacecraft technology improvements in terms of the changes in cash flow, present value of cash flows, and return on investment that may result from the use of new and/or improved spacecraft technology for specific types of private sector communications satellite missions.

Attention has focused on business ventures providing fixed satellite services (FSS) and direct broadcast services (DBS). The establishment of the impacts on communications satellite business ventures requires the formulation of typical communications satellite business ventures, the simulation modeling of these ventures, the establishment of appropriate business and technology data bases, and the analysis of the business ventures with and without NASA investment in spacecraft technology programs.

Typical FSS and DBS communications satellite business ventures have been formulated based upon discussions with the carriers, FCC filings and previous experience. The structuring of the business ventures includes a determination of the services to be provided (i.e., protected and non-protected transponders) and the demand for these services, sparing arrangements, use of insurance, number of satellites and their desired launch dates, anticipated launch delays, etc. Specific data pertaining to typical overhead rates, G&A rates, market forecasts, and other factors have been obtained. Typical spacecraft have been configured for use in the FSS and DBS business ventures. The baseline spacecraft configurations are based upon a technology base in the absence of NASA technology development programs. Spacecraft are then reconfigured so as to encompass a technology base with a specified (by NASA) set of NASA technology development programs. The spacecraft configurations provide inputs to the financial analysis such as subsystem reliability and consequences of failures (i.e., graceful degradation), number

of transponders, and recurring and non-recurring costs.

The spacecraft characteristics as determined by available technology (i.e., with and without NASA programs) are provided as input, together with business scenario data, to a financial simulation model. It must be emphasized that since much of the data can best be characterized as uncertainty variables (that is, specific single valued projections cannot be made with confidence and the variables can best be described in terms of ranges of uncertainty and the form of the uncertainty), the analysis considers the uncertainty and risk dimensions. This is particularly important since many technology development programs are specifically aimed at influencing private sector investment decisions through a reduction in perceived risk. [6]

A financial simulation model was developed [Reference 8 served as the basis for this work] that allows the financial impact of S/C technology programs to be evaluated for a broad range of point-to-point/point-to- multipoint (i.e., fixed satellite services, FSS) and direct broadcast communication satellite (DBS) business scenarios. The model allows a broad range of communications satellite business ventures to be simulated explicitly and quantitatively taking into account uncertainty, unreliability and resulting risk. The model provides a means for evaluating the financial impacts of S/C technology programs and orbital transfer programs on private sector business ventures. This is accomplished by reconfiguring S/C taking into account the anticipated results of the technology programs. The resulting S/C configurations are communicated to the financial model through specific estimates of cost,

performance and reliability. These estimates are then combined with a business scenario (i.e., number of satellites as a function of time, number and type of transponders, demand for transponders, communications services provided, launch system scenario as a function of time, likely launch time delays, transfer time from LEO to GEO, cost of insurance, satellite control operations expense, G&A expense, etc.) to establish annual profit (loss), annual cash flow, cumulative cash flow, ROA, payback period, and ROI. The financial performance measures are all described by probability distributions (i.e., risk profiles) since demand, price and cost uncertainties (i.e., uncertainty profiles) and subsystem reliability are considered.

The impact of the technology programs are assessed in terms of the differences that result in financial performance measures which are the result of differences in S/C performance and cost attributes resulting from the technology programs. Two analyses are necessary for assessing the financial impacts of the S/C technology programs on a communications satellite business venture; one analysis based upon a satellite configured in the absence of the technology program (i.e., the base case), and a second analysis based upon a satellite configuration incorporating the assumed results of the technology program. The difference in the financial results is therefore assumed to be directly attributable to the technology program.

Analyses have been performed and results obtained for on-board propulsion (ion-thrusters) and power system (solar cells) technology programs as specified by NASA. Satellites have been

configured and costed both with and without the technology programs. Differences in both performance and cost attributes have been taken into account in the financial analysis. Results are presented in the following pages that indicate the likely financial impacts of these technology programs on typical FSS and DBS business ventures utilizing spin and three-axis stabilized spacecraft.

The financial simulation model, DOMSAT II, is a stochastic (Monte Carlo) simulation model that represents a broad range of fixed satellite and direct broadcast service communications satellite business ventures. The Model is specifically configured to assess the impacts of the S/C technology and related programs upon the financial performance of FSS and DBS business ventures. The DOMSAT II Model is implemented on an IBM-PC (see Appendix A for the Model description, and Appendix B for the Model user and programmer documentation) with input data provided using LOTUS 123. The LOTUS data file is then read by the Model which is written in FORTRAN.

The analysis of a spacecraft technology program consists of establishing a baseline communications satellite business venture scenario in terms of a baseline spacecraft configuration. The spacecraft cost and performance attributes are specified to the DOMSAT II Model along with the specification of the business scenario. The Model then establishes the financial performance measures of the business as a function of time. The effects of S/C technology programs are assessed by specifying the anticipated results of the technology program, reconfiguring the spacecraft utilizing the assumed new level of technology, costing

the spacecraft and specifying the cost and performance attributes to the DOMSAT II Model. New financial performance measures are thence developed utilizing the new spacecraft in the specified business scenario.

The resulting financial information will provide insight into the financial implications of NASA technology programs on typical FSS and DBS communications satellite business ventures. The financial information includes both expected values and standard deviations so that the effects of the government programs can be observed in the form of both changes in expected values and changes in risk levels. Both of these dimensions are important since investment decisions take into account both the expected and risk dimensions.

This report describes the methodology developed for evaluating NASA spacecraft and related programs in terms of their impacts on communications satellite business ventures and presents results of the analyses performed on two spacecraft technology programs (ion-thrusters for on-orbit propulsion and improved solar cells). The methodology is described in Section 2 with details presented in the appendicies. The general description of business scenarios is discussed in Section 3. U.S. and foreign S/C technologies (ion-thrusters and solar cells) are described in Section 4. The S/C configurations for both the FSS and DBS missions with and without the technology programs are described in Section 5. The business ventures are described and results of the financial analyses of the technology programs on the FSS and DBS business ventures are summarized in Section 6.

The implications of the technology programs on spacecraft markets is discussed in Section 7, both from the points of view of the specific scenarios considered and the communications satellite industry. Other applications of the methodology are discussed in Section 8.

2. METHODOLOGY

2.1 Introduction

The objective of the reported effort was to develop an economic evaluation and planning capability appropriate for the evaluation of spacecraft (S/C) technologies such as space power and on-orbit propulsion systems, to perform technology assessments and projections and to then, using the developed capability, assess the impact of NASA and foreign technology programs on typical fixed satellite service (FSS) and direct broadcast service (DBS) communications satellite business ventures. An additional objective was to perform the analysis of the impacts of the spacecraft technology programs in much the same way as might be performed by commercial ventures so as to provide credible results for assessment by the private sector. Figure 2.1 presents an overview of the methodology for assessing the impacts of NASA S/C technology programs on communications satellite business ventures.

Using typical FSS and DBS missions, general business scenarios were developed that served as the basis for the simulation modeling and the basis for assessing the impact of NASA S/C technology programs. The business scenario information included sparing concepts, demand characteristics (for example, protected and preemptible transponders), insurance concepts, financial treatment of failures, failure/recovery concepts, as well as other factors that influenced the structure and configuration of the DOMSAT II financial simulation model. The

business scenario information also included quantitative data such as typical levels of general and administrative (G&A) expense, R&D expense and other parameters that are necessary to characterize typical business ventures. The business scenario information was obtained from the published literature, including FCC filings, as well as direct discussions with the carriers.

Typical sets of performance characteristics were established for the FSS and DBS communications missions. These performance characteristics, based upon mission requirements (i.e., channel capacity, reliability, etc.), served as the initial basis for establishing spacecraft configurations. Tables 2.1 and 2.2 summarize satellite performance characteristics (as well as other factors). Based upon these data, the availability of detailed design data, and the desire to consider both spin- and three-axis stabilized configurations in combination with both low and high power configurations, it was decided to consider a spin stabilized low power S/C configuration as the basis for the FSS business venture. It was also decided to consider a three-axis stabilized high power S/C configuration as the basis for the DBS business venture. As will be described in following paragraphs, both of these configurations were modified to take advantage of on-orbit propulsion and improved solar cell capabilities assumed to result from NASA specified technology programs. The spacecraft performance characteristics were thus established for both the DBS and FSS communications satellite missions in the 1990 time frame.

The performance characteristics included radiated power,

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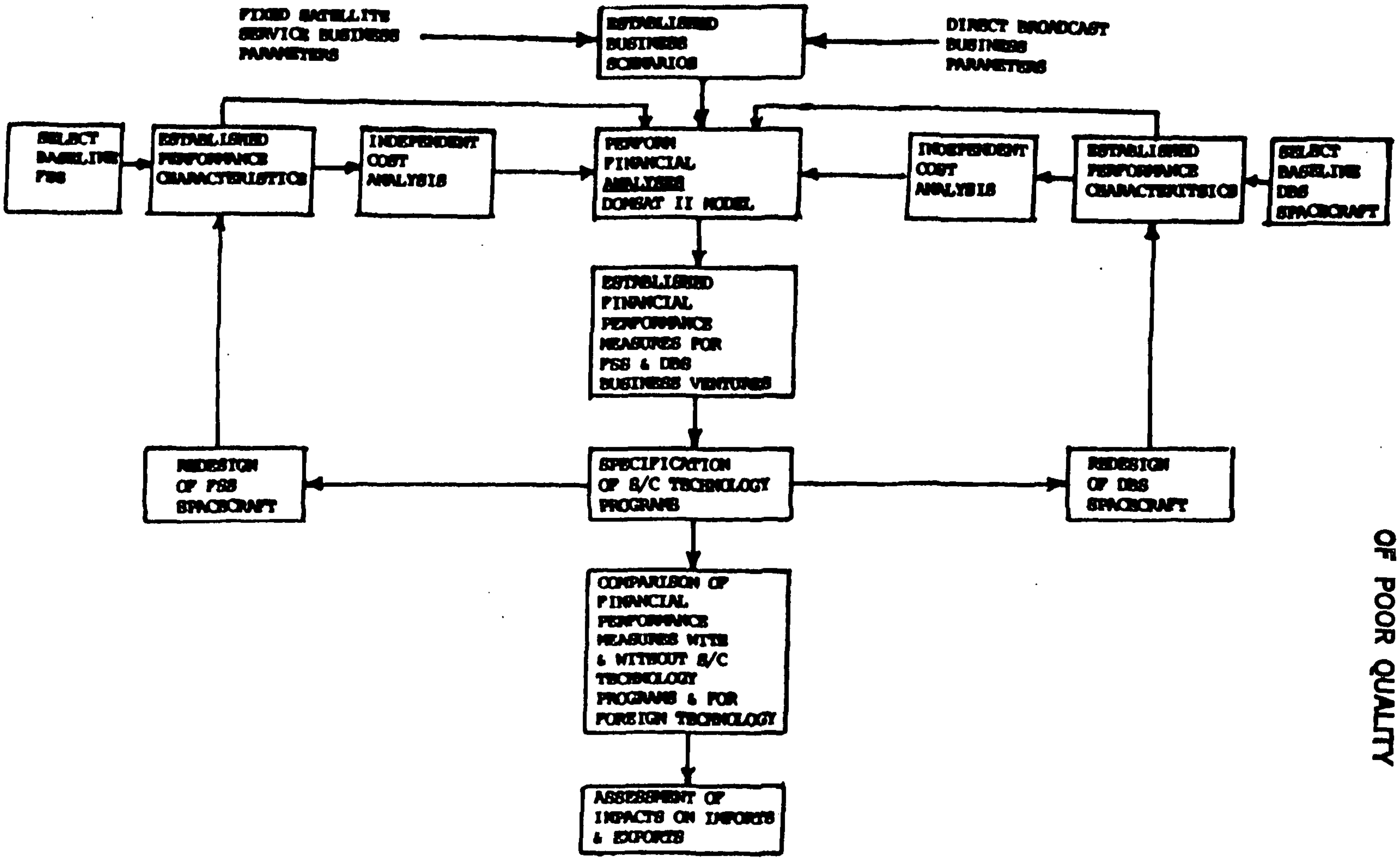

FIGURE 2.1 OVERVIEW OF METHODOLOGY FOR ASSESSING IMPACTS OF NASA S/C TECHNOLOGY PROGRAMS ON COMMUNICATIONS SATELLITE BUSINESS VENTURES

TABLE 2.1 DOMESTIC FIXED SERVICE TECHNICAL CHARACTERISTICS

Satellite Name	Operator	Launch Dates	Effective Transponders per Satellite	Frequency	Design Life	Stabilization	Prime Power (Watts)	Bandwidth (MHz)	Redundancy	Launch Vehicle
ABCI 1	Adv Bus Comm	1986	20	Ku	10					
ABCI 2		1986	20	Ku	10					
Aurora I	Alascom, Inc.	1982	24	C	10	3 axis	1450BOL/1100EOL			Delta 3924
Aurora II		1989	24	C	10					
Aurora III		1991	24	C	10					
ABC 1	American	1985	18/6	C/Ku	10	3 axis or spin		36/72	7 for 6	Thor Delta,
ABC 2	Satellite	1986	18/6	C/Ku	10	3 axis or spin		36/72	7 for 6	3920/PAM,
ABC 3	Company	1987	18/6	C/Ku*	10	3 axis or spin		36/72	7 for 6	(STS, Ariane)
ABC 4		1989	24/19/3	C/Ku/Ka	10	3 axis or spin		36/54/500	7 for 6	STS or Ariane
ABC 5		1989	24/19/3	C/Ku/Ka	10	3 axis or spin		36/54/500	7 for 6	STS or Ariane
Anik A2	Telsat	1973	12	C	7					Delta
Anik A3	Canada	1975	12	C	7					Delta
Anik B		1978	12/6	C/Ku	7	3 axis	840BOL/635EOL	72		Delta
Anik C1		1982	16	Ku	10	Spin	>900 BOL	54		
Anik C2		1983	16	Ku	10	Spin	>900 BOL	54		
Anik C3		1982	16	Ku	10	Spin	>900 BOL	54		STS
Anik D1		1982	24	C	10	Spin	1000 BOL	36		Delta 3920
Anik D2		1984	24	C	10	Spin	1000 BOL	36		STS
CCC1	Columbia		24	C/Ku	10					
CCC2	Comm. Corp.		24	C/Ku	10					
Comstar D1	Comsat General	1976	24	C	7	Spin	760BOL/360EOL	36	no redundancy	Atlas Centaur
Comstar D2	For AT&T/GTE	1976	24	C	7	Spin	760BOL/360EOL	36	no redundancy	Atlas Centaur
Comstar D3		1978	24	C	7	Spin	760BOL/360EOL	36	no redundancy	Atlas Centaur
Comstar D4		1981	24	C	7	Spin	760BOL/360EOL	36	no redundancy	Atlas Centaur
Comstar K1	Comsat General		16	Ku	10 ML			54		STS/Pam-DII
Comstar K2			16	Ku	10 ML			54		STS/Pam-DII
Comstar K3 (in orbit spare)			16	Ku	10 ML			54		STS
Digisat IA	Digital Telsat	1988	24	Ku	10					
Digisat II		1988	24	Ku	10					
Digisat IB		1988	24	C	10					
Equastar	Equatorial	1987	24	C	10	3 axis or spin			5 for 4	Delta 390, STS
		1988	24	C	10	3 axis or spin			5 for 4	Delta 390, STS
Ford 1	Ford Aerospace	1988	48 (24/24)	C/Ku	10 ML	3 axis	3000 EOL	36	9 for 6 TWT/	STS, Ariane IV
Ford 2		1988	48 (24/24)	C/Ku	10 ML	3 axis	3000 EOL	36	7 for 6 SSPA	STS, Ariane IV
Ford 3		1988	48 (24/24)	C/Ku	10 ML	3 axis	3000 EOL	36		STS, Ariane IV
Galaxy I	Hughes Comm.	1983	24	C	9	Spin	990 BOL	36	6 spare TWTAs	Delta 3920
Galaxy II	Galaxy, Inc.	1983	24	C	9	Spin	990 BOL	36	6 spare TWTAs	Delta
Galaxy III		1984	24	C	9	Spin	990 BOL	36	6 spare TWTAs	STS
Galaxy IV			24	C	9	Spin				
Galaxy H-5		1986	16	Ku	10	Spin				
Galaxy H-6		1987	16	Ku	10	Spin				
Galaxy H-7		1988	16	Ku	10	Spin				

* ABC requests to use Ku band temporarily

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TABLE 2.1 DOMESTIC FIXED SERVICE TECHNICAL CHARACTERISTICS (CONTINUED)

Satellite Name	Spacecraft Mass (kilograms)	Batteries	EIRP (dBW)	Minimum Life (yrs)	Beam Width	Pointability (Pointing Accuracy)	Capacity	Sources
ABCI 1								3
ABCI 2								3
Aurora I		NiCad						3,11
Aurora II								3
Aurora III								3
ASC 1	<1400-Delta		34-36	7.5	6.8°x3.5°	+0.10° EW/NS		3,17
ASC 2	<1400-Delta		34-36	7.5	6.8°x3.5°	+0.10° EW/NS		3,17
ASC 3	<1400-Delta		34-36	7.5	6.8°x3.5°	+0.10° EW/NS		3,18,19
ASC 4	2175-STS, 2605-Ariane	NiHy	34-51.5	8.5 NFLML	6.8°x3.5°	+0.10° EW/NS		3,20
ASC 5	2175-STS, 2605-Ariane	NiHy	34-51.5	8.5 NFLML	6.8°x3.5°	+0.10° EW/NS		3,20
Anik A2								3
Anik A3								3
Anik B	903-TOW, 461-OBM							3,21
Anik C1	1140, 563 (OBM)	NiCad	46.5-48					3,4,23
Anik C2	1140, 563 (OBM)	NiCad	46.5-48					3,4,23
Anik C3	1140, 563 (OBM)	NiCad	46.5-48					3,4,23
Anik D1	634 (BOL)	NiCad	36 (min)	8			960 one way voice circuits or one color	3,4,22
Anik D2	634 (BOL)	NiCad	36 (min)	8			TV program at 36dBW	3,4,22
CCC1								
CCC2								
Comstar D1							over 10,000 2 way simultaneous tele-	3,24,25
Comstar D2							phone conversations per satellite	3,24,25
Comstar D3							over 10,000 2 way simultaneous tele-	3,24,25
Comstar D4							phone conversations per satellite	3,24,25
Comstar K1	1864 (TOW)		47-50			+0.1°	18,000 voice circuits simultaneously	3,26
Comstar K2	1864 (TOW)		47-50			+0.1°	18,000 voice circuits simultaneously	3,26
Comstar K3 (in orbit spare)	1864 (TOW)		47-50			+0.1°	18,000 voice circuits simultaneously	3,26
Digisat IA								3
Digisat II								3
Digisat IB								3
Equastar								3,27 3,27
Ford 1	7691-launch, 1360-BOL	NiHyd	35-48			+0.08°		3,28-30
Ford 2	7691-launch, 1360-BOL	NiHyd	35-48			+0.08°		3,28-30
Ford 3	7691-launch, 1360-BOL	NiHyd	35-48			+0.08°		3,28-30
Galaxy I	654 (BOL)	NiCad	34					3,30,31
Galaxy II	654 (BOL)	NiCad	34					3,30,31
Galaxy III	654 (BOL)	NiCad	34					3,30,31
Galaxy IV								3
Galaxy H-5								3
Galaxy H-6								3
Galaxy H-7								3

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TABLE 2.1 DOMESTIC FIXED SERVICE TECHNICAL CHARACTERISTICS

Satellite Name	Operator	Launch Dates	Effective Transponders per Satellite	Frequency	Design Life	Stabilization	Prime Power (Watts)	Bandwidth (MHz)	Redundancy	Launch Vehicle
Gstar A-1	GTE Satellite	1984	16	Ku	10 ML	3 axis	1900	54	19 for 14/3 for 2	STS, Delta 3920, Ariane 3
Gstar A-2		1984	16	Ku	10	3 axis	1900	54	19 for 14/3 for 2	STS/PAMD2,Delta 3290
Gstar A-3		1987	16	Ku	10	3 axis	1900	54	19 for 14/3 for 2	STS/PAMD2,Delta 3290
Gstar A-4 (ground spare)				Ku	10	3 axis	1900	54	19 for 14/3 for 2	
	Martin Marietta	1988	28	Ku	10					
Mexico 1	Mexico	1985+	18/4	C/Ku	9					
Mexico 2										
RSI I	Rainbow	1985	16	Ku	8-10			54		
RSI II	Satellite, Inc.	1986	16	Ku	8-10			54		
RSI II		1987	20	Ku	8-10			43		
RSI IV		1987	20	Ku	8-10			43		
Satcom IIIR	RCA America	1981	24	C	10	3 axis	1000 BOL	36	7 for 6 TWTA	Delta 3910/PAMD
Satcom IV		1982	24	C	10	3 axis	985BOL/700EOL	36	7 for 6 TWTA	Delta
Satcom IR		1983	24	C	10	3 axis	1450BOL/1100EOL	36	7 for 6 SSPA	Delta 3910/PAMD
Satcom IIR		1983	24	C	10	3 axis	1450BOL/1100EOL	36	7 for 6 SSPA	Delta 3910/PAMD
Satcom VI		1986	24	C	10	3 axis	1450BOL/1100EOL	36	7 for 6 SSPA	Delta 3910/PAMD
Satcom VII		1983	24	C	10	3 axis	1579BOL/1112EOL	36	7 for 6 SSPA	STS/PAMD or Ariane
Satcom VIII		1990	24	C	10	3 axis	1579BOL/1112EOL	36	7 for 6 SSPA	STS/PAMD or Ariane
Satcom IX		1992	24	C	10	3 axis	1579BOL/1112EOL	36	7 for 6 SSPA	STS/PAMD or Ariane
Satcom K1		1985	16	Ku	10	3 axis	1395 BOL	54	5 for 4	STS or Ariane
Satcom K2		1985	16	Ku	10	3 axis	1395 BOL	54	5 for 4	STS or Ariane
Satcom K3		1987	16	Ku	10	3 axis	1395 BOL	54	5 for 4	STS or Ariane
Satcom K5		1988	16	Ku	10	3 axis	2440 BOL	54	11 for 8 TWTA	STS/PAMDII
Satcom K6		1989	16	Ku	10	3 axis	2440 BOL	54	11 for 8 TWTA	STS/PAMDII
Satcom K7		1991	16	Ku	10	3 axis	2440 BOL	54	11 for 8 TWTA	STS/PAMDII
Satcom K4 (ground spare)										
Satcom Hybrids H1		1988	24/16	C/Ku	10		5228BOL/3921BOL	36/54	7 for 6 SSPA/	STS/Ariane IV
H2		1989	24/16	C/Ku	10		5228BOL/3921BOL	36/54	11 for 8 TWTA	STS/Ariane IV
H3		1991	24/16	C/Ku	10		5228BOL/3921BOL	36/54	"	STS/Ariane IV
SBS 1	Satellite	1980	10	Ku	7	Spin	1118 BOL	43	16 for 10 TWTA	Delta 3910
SBS 2	Business	1981	10	Ku	7	Spin	1118 BOL	43	16 for 10 TWTA	Delta 3910 (Thor)
SBS 3	Systems	1982	10	Ku	7	Spin	1118 BOL	43	16 for 10 TWTA	
SBS 4		1984	10	Ku	7		1078 BOL	43	16 for 10 TWTA	
SBS 5		1986	14	Ku	10		1104BOL/899EOL	43/110	24 for 16 TWTA	
SBS 6		1987	14	Ku	10					
SBS 7		1987	19	Ku	10					
SBS 8		1988	19	Ku	10					
SBS 9		1990	19	Ku	10					

TABLE 2.1 DOMESTIC FIXED SERVICE TECHNICAL CHARACTERISTICS (CONTINUED)

Satellite Name	Spacecraft Mass (kilograms)	Batteries	EIRP (dBW)	Minimum Life (yrs)	Beam Width	Pointability (Pointing Accuracy)	Capacity	Sources
Gstar A-1	1259-TOW, 639-MB						Two satellites can transmit 30,000 simultaneous telephone conversations, 300 two way video conferences or combinations of both. Each transponder has a capacity of 60 megabits/sec.	1-4
Gstar A-2	1259-TOW, 639-MB							2-4
Gstar A-3	1323	NiHyd	40-42					1-4
Gstar A-4 (ground spare)								3,5
Mexico 1								3
Mexico 2								
RBI I								3
RBI II								3
RBI II								3
RBI IV								3
Satcom IIIR	1109-TOW, 585-OSW	NiCad					1,400 voice circuits, one FM/color TV transmission or 64 megabites/sec. (Satcom IV has 1,000 voice circuits)	3,4,6
Satcom IV	1109-TOW, 585-OSW	NiCad						3,4,6,7
Satcom IR	1109-TOW, 585-OSW	NiCad		9-fuel life		+0.01˚(normal)		3,4,8-10
Satcom IIR	1109-TOW, 585-OSW	NiCad		9-fuel life		+0.01˚(normal)		3,4,8,10
Satcom VI	1109-TOW, 585-OSW	NiCad		9-fuel life		+0.01˚(normal)		3,4,8,10,11
Satcom VII	1250-TOW, 509-OODW	NiHyd	36 (CONUS)			+0.07˚ NS/EW		3,4,11,12
Satcom VIII	1250-TOW, 509-OODW	NiHyd	36 (CONUS)			+0.07˚ NS/EW		3,12
Satcom IX	1250-TOW, 509-OODW	NiHyd	36 (CONUS)			+0.07˚ NS/EW		3,13
Satcom K1	664-BOL		44-50 (nominal)					3,13
Satcom K2	664-BOL		44-50 (nominal)					3,13
Satcom K3	664-BOL		44-50 (nominal)					3,12,13
Satcom K5	1939-TOW, 775-OODW	NiHyd	44-50 (nominal)	10-fuel life		+0.07˚ NS/EW		3,12,13
Satcom K6	1939-TOW, 775-OODW	NiHyd	44-50 (nominal)	10-fuel life		+0.07˚ NS/EW		3,12,13
Satcom K7	1939-TOW, 775-OODW	NiHyd	44-50 (nominal)	10-fuel life		+0.07˚ NS/EW		
Satcom K4 (ground spare)								
Satcom Hybrids								
H1	2648-STS, 2375-Ariane	NiHyd	36-39/44-52.8					3,12
H2	2648-STS, 2375-Ariane	NiHyd	36-39/44-52.8					3,12
H3	2648-STS, 2375-Ariane	NiHyd	36-39/44-52.8					3,12
SBS 1	590-BOL	NiCad				+0.05˚ EW/NS	1,250 two way telephone conversations per channel, 10 simultaneous color TV transmissions, or combinations of these	3,14,15
SBS 2	590-BOL	NiCad				+0.05˚ EW/NS		3,14,15
SBS 3	590-BOL	NiCad				+0.05˚ EW/NS		3,14,15
SBS 4		NiCad				+0.05˚ EW/NS		3,14-16
SBS 5						+0.05˚ EW/NS		3,16
SBS 6	1253-TOW	NiCad						3,16
SBS 7								
SBS 8								
SBS 9								

TABLE 2.1 DOMESTIC FIXED SERVICE TECHNICAL CHARACTERISTICS

Satellite Name	Operator	Launch Dates	Effective Transponders per Satellite	Frequency	Design Life	Stabilization	Prime Power (Watts)	Bandwidth (MHz)	Redundancy	Launch Vehicle
Spacenet 1	GTE Spacenet	1984	18/6	C/Ku	10	3 axis	1212	36/72	7 for 6	Ariane 1
Spacenet 2		1984	18/6	C/Ku	10	3 axis	1212	36/72	7 for 6	Ariane 2
Spacenet 3		1985	18/6	C/Ku	10	3 axis	1212	36/72	7 for 6	Ariane 3
Spacenet 4		1986	12/6*	C/Ku		3 axis		36/72	7 for 6	
Spotnet(K) 1	National Exchange, Inc.	1987	24	Ku	10					
Spotnet(K) 2		1987	24	Ku	10					
Spotnet(K) 3		1987	24	Ku	10					
Spotnet(K) 4		1987	24	Ku	10					
Spotnet(C) 1		1987	24	C	9					
Spotnet(C) 2		1987	24	C	9					
Telstar 301	AT&T Comm.	1983	24	C	10	Spin	917BOL/670EOL	36	18 SSPA,12 TWTA	Delta 3920, STS, or Ariane
Telstar 302		1984	24	C	10	Spin	917BOL/670EOL	36	18 SSPA,12 TWTA	
Telstar 303		1985	24	C	10	Spin	917BOL/670EOL	36	18 SSPA,12 TWTA	
Telstar 304		1988	24	C	10	Spin	917BOL/670EOL	36	18 SSPA,12 TWTA	
USAT 1	U.S. Satellite Systems, Inc.	1986	20	Ku	10	3 axis or Spin	1680 BOL (Eq)	43	6 for 5	Delta 3920 PAM, STS PAMD, or Ariane
USAT 2		1987	20	Ku	10	3 axis or Spin	1680 BOL (Eq)	43	6 for 5	
USAT 3		1988	20	Ku	10	3 axis or Spin	1680 BOL (Eq)	43	6 for 5	
USAT 4		1989	20	Ku	10	3 axis or Spin	1680 BOL (Eq)	43	6 for 5	
Westar III	Western Union Telegraph	1979	12	C	7	Spin	262 BOL	36		Thor Delta 2914
Westar IV		1982	24	C	10	Spin	935BOL/685EOL	36		Thor Delta 3910/PAMD
Westar V		1982	24	C	10	Spin	935BOL/685EOL	36		Thor Delta 3910/PAMD
Westar VI failed		1984	24	C	10					
Westar VII		1984	24	C	10					
Westar VIII		1987	24	C	10			54		
Westar IX		1992	24	C	10			54		
Westar X		1994	24	C	10			54		
Westar XI		1994	24	C	10			54		
Westar XII		1995	24	C	10					
Westar XIII		1996	24	C	10					
Westar XIV		1996	24	C	10					
Westar XV		1997	24	C	10					
Westar XVI		1998	24	C	10					
Westar XVII			24	C	10					
Westar A			16	Ku	10					
Westar B			16	Ku	10					
Westar C			16	Ku	10					
Westar D			16	Ku	10					
Westar E			16	Ku	10					
Westar F			16	Ku	10					

* The 6 Ku-band transponders will be used until the 1987 launch of GSTAR A-3, at which point they will become in-orbit spares

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TABLE 2.1 DOMESTIC FIXED SERVICE TECHNICAL CHARACTERISTICS (CONTINUED)

Satellite Name	Spacecraft Mass (kilograms)	Batteries	EIRP (dBW)	Minimum Life (yrs)	Beam Width	Pointability (Pointing Accuracy)	Capacity	Sources
Spacenet 1	1195-TOW, 692-BOL	NiHyd	33-36	7.5-fuel life				3,30,32,33
Spacenet 2	1195-TOW, 692-BOL	NiHyd	33-36	7.5-fuel life				3,30,32,33
Spacenet 3	1195-TOW, 692-BOL	NiHyd	33-36	7.5-fuel life				3,30,32,33
Spacenet 4	1195-TOW, 692-BOL	NiHyd	33-36					3,30,32,33
Spotnet(K) 1								3
Spotnet(K) 2								3
Spotnet(K) 3								3
Spotnet(K) 4								3
Spotnet(C) 1								3
Spotnet(C) 2								3
Telstar 301	250-TOW, 659-OBW	NiCad	35				Long distance call capacity of 21,600	3,4,25,34
Telstar 302	250-TOW, 659-OBW	NiCad	35				Long distance call capacity of 21,600	3,4,25,34
Telstar 303	250-TOW, 659-OBW	NiCad	35				Long distance call capacity of 21,600	3,4,25,34
Telstar 304	250-TOW, 659-OBW	NiCad	35				Long distance call capacity of 21,600	3,4,25,34
USAT 1	1251-TOW,	NiHyd	38-51	8-fuel life				3,35,36
USAT 2	668-OBW,	NiHyd	38-51	8-fuel life				3,35,36
USAT 3	551-OODW	NiHyd	38-51	8-fuel life				3,35,36
USAT 4	*	NiHyd	38-51	8-fuel life				3,35,36
Westar III	298-OBW						7,200 one way voice circuits, one color TV signal or 6 megabites/sec. digital	3,4,37
Westar IV	581-BOL	NiCad	27.2-34			+0.05'	7,200 one way voice circuits, one full-color TV signal with audio or 64 mega-bits/sec. digital traffic	3,4,38
Westar V	581-BOL	NiCad	27.2-34			+0.05'		3,4,38
Westar VI failed	611-BOL	NiCad	27.2-34			+0.05'		3,4,38
Westar VII								
Westar VIII								
Westar IX								
Westar X								
Westar XI								
Westar XII								
Westar XIII								
Westar XIV								
Westar XV								
Westar XVI								
Westar XVII								
Westar A								
Westar B								
Westar C								
Westar D								
Westar E								
Westar F								

TABLE 2.2 DIRECT BROADCAST SATELLITES TECHNICAL CHARACTERISTICS

DBS Satellite Operator	Launch Dates	Channels or Transponders per Satillite	Frequency	Design Life (years)	Stabilization	Prime Power (watts)	Band Width (MHz)	Amplifier Redundancy	Launch Vehicle	Spacecraft Mass (kilograms)
STC 1		3	17/12	7 ML	Spin or body	2000 (BOL)	24	1 for 1 TWTA	STS or Ariane	650 (OSW)
2		3	17/12	7 ML	Spin or body	2000 (BOL)	24	1 for 1 TWTA	STS or Ariane	650 (OSW)
3		3	17/12	7 ML	Spin or body	2000 (BOL)	24	1 for 1 TWTA	STS or Ariane	650 (OSW)
4		3	17/12	7 ML	Spin or body	2000 (BOL)	24	1 for 1 TWTA	STS or Ariane	650 (OSW)
(2 on-orbit spares)										
RCA 1	1989	16	17/12	7 ML	3 axis	5400 (BOL)	24	6 for 4 TWTAs	STS	(2500 (TOW),
2	1991	16	17/12	7 ML	3 axis	5400 (BOL)	24	6 for 4 TWTAs	STS	(1332 (BOL),
(ground spare) 3		16	17/12	7 ML	3 axis	5400 (BOL)	24	6 for 4 TWTAs	STS	(977 (OODW)
National Christian Network		6	17/12			4770 (BOL)	24	6 redundant RF power amplifiers	STS	2190 (TOW), 887 (OODW)
DBSC 1		14	17/12				24		STS, Ariane, Atlas Centuar	
DBSC 2		14	17/12				24			
DBSC 3		14	17/12				24			
DBSC 4 (spare)		14	17/12				24			
Dominion Video 1		6	17/12	10 ML	Spin and 3 axis		24	7 for 3 TWTAS	STS/PAMD, Ariane	1010 (BOL)
Satellite System 2		6	17/12	10 ML	Spin and 3 axis		24	7 for 3 TWTAS	STS/PAMD, Ariane	1010 (BOL)
3			17/12	10 ML	Spin and 3 axis		24	7 for 3 TWTAS	STS/PAMD, Ariane	1010 (BOL)
4			17/12	10 ML	Spin and 3 axis		24	7 for 3 TWTAS	STS/PAMD, Ariane	1010 (BOL)
(one ground spare)										
Spotret (DBS) 1	1988	16	17/12	9 ML	Spin or 3 axis		24	8 spare TWTAs	STS or Ariane	2045-2273 (TOW)
National Ex., Inc. 2		16	17/12	9 ML	Spin or 3 axis		24		STS or Ariane	2045-2273 (TOW)
(ground spare) 3		16	17/12	9 ML	Spin or 3 axis		24		STS or Ariane	2045-2273 (TOW)
Advanced Communications Corp. (one on-orbit spare)		6	17/12	7 OL			24	1 for 1		2045-2273 (TOW)

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TABLE 2.2 DIRECT BROADCAST SATELLITES TECHNICAL CHARACTERISTICS (CONTINUED)

DBS Satellite Operator		Pointability (Pointing Accuracy)	Batteries	EIRP (dBW)	Minimum Power (watts)	Capacity	Power Amplifier Output (watts per channel)	Sources
STC	1	+0.1°	NiCad or Hyd	58.2-55.1	1700 (EOL)	3 standard video 16 MHz BW	215 (BOL), 185 (EOL)	39,40
	2	+0.1°	NiCad or Hyd	58.2-55.1	1700 (EOL)	2 alt HDTV channels 28 MHz	215 (BOL), 185 (EOL)	39,40
	3	+0.1°	NiCad or Hyd	58.2-55.1	1700 (EOL)	and 100 MHz BW	215 (BOL), 185 (EOL)	39,40
	4	+0.1°	NiCad or Hyd	58.2-55.1	1700 (EOL)		215 (BOL), 185 (EOL)	39,40
(2 on-orbit spares)								
RCA	1	+0.05°	NIHyd	51	4300 (after 10 yrs)		100	41
	2	+0.05°	NIHyd	51	4300 (after 10 yrs)		100	41
(ground spare)	3	+0.05°	NIHyd	51	4300 (after 10 yrs)		100	41
National Christian Network		+0.05°		54	3600 (7 yrs)	6 standard TV channels	230	40,42
		+0.05°						
DBSC 1		+0.1°		54-58			200	43,44
DBSC 2		+0.1°		54-58			200	43,44
DBSC 3		+0.1°		54-58			200	43,44
DBSC 4 (spare)		+0.1°		54-58			200	43,44
Dominion Video Satellite System	1			57	4000 (EOL)		230	45
	2			57	4000 (EOL)		230	45
	3			57	4000 (EOL)		230	45
	4			57	4000 (EOL)		230	45
(one ground spare)								
Spotret (DBS)	1	+0.1°					50	46
National Ex., Inc.	2	+0.1°					50	46
(ground spare)	3	+0.1°					50	46
Advanced Communications Corp. (one on-orbit spare)		+0.1°		54			215 (BOL), 185 (EOL)	40,47

frequency, number of beams, beam-width, pointability, stability, life characteristics, number of transponders, as well as other factors.

A financial simulation model was developed and used to assess the impact of the spacecraft technology programs on the typical FSS and DBS business ventures. The model is stochastic (Monte Carlo) and based upon the DOMSAT Model principals.[48,49] The model explicitly allows for the consideration of pertinent subsystem performance characteristics including reliabilities and various cost, expense, capital expenditure and timing uncertainties. The result is the determination of a range of financial performance measures including quantitative measures of risk. This allows both the expected value and risk dimensions to be taken into account in the assessment of the value of the introduction of new technologies.

Typical FSS and DBS business venture scenarios were developed and analyzed based upon base case satellites — a spin-stabilized configuration for the FSS system and a three-axis configuration for the DBS system (these are described in detail in Section 4). NASA specified the likely outcomes of an ion-thruster technology program and a Gallium Arsenide solar array program. These new technology capabilities were then considered and the two base case satellites reconfigured to make best use of the attributes of the technologies. The satellites were reconfigured to maximize the financial performance of the business ventures and not to minimize the cost of the satellites. It must be emphasized that one technology was not simply substituted for another technology but the satellite was

reconfigured (and recosted) so as to fully take advantage of the attributes of the new technologies.

Both nonrecurring and unit recurring costs were estimated for each satellite configuration (including the base cases). The RCA PRICE cost estimating model was used for this purpose. Changes in reliability were also estimated as well as other spacecraft attributes. These factors were then used in the same business scenarios as evaluated with the base case satellites to establish the resulting changes in the business ventures financial performance measures. The changes in the financial performance measures were therefore assumed to result from the technology programs.

The financial performance measures resulting from use of the new technology satellites were evaluated and the likely impacts on investment decisions established. Foreign spacecraft technology programs (on-orbit propulsion and solar cell) were reviewed and assessments made, taking into account the financial implications of the analyzed technology programs, of the likely impact of these programs with and without the NASA technology programs on U.S. imports and exports. It must be emphasized that even though these assessments were based upon a very limited assessment of business scenarios, a number of conclusions may be drawn.

Discussions with the carriers and review of the FCC filings indicated the need to consider the provision of multiple communications services. Typical levels of service are indicated in Table 2.3 and current pricing policies for these services are

TABLE 2.3 LEVELS OF PROTECTION OFFERED BY DIFFERENT CARRIERS

AT&T	GTE	RCA	ASC	WU
PLATINIUM	PROTECTED	PROTECTED	PROTECTED	PROTECTED
GOLD	PROTECTED/ PREEMPTIBLE			
	UNPROTECTED	UNPROTECTED/ NONPREEMPTIBLE		UNPROTECTED
BRONZE	PREEMPTIBLE	UNPROTECTED/ PREEMPTIBLE		PREEMPTIBLE

NOTE: THE ROWS INDICATE EQUIVALENT LEVELS OF SERVICE

summarized in Table 2.4. The DOMSAT II Model therefore considers the following four levels of service and allows a pricing policy to be specified for each:

* Protected Service - protection is provided through provisions of spares and preemptible transponders.

* Protected/Preemptible Service - protection is provided through available spares and preembtible transponders. This service may be preempted if protected users require transponders.

* Unprotected/Non-Preemptible Service - a replacement transponder is not guaranteed but service may not be interrupted to provide service to other users.

* Preemptible - Protection is not provided and transponder may be preempted if the transponder is required by a protected user.

TABLE 2.4 ANNUAL TRANSPONDER LEASE RATES IN THOUSAND OF DOLLARS

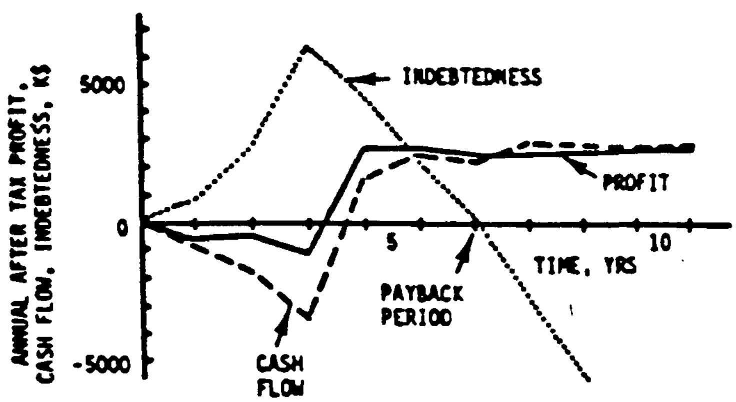
SERVICE	AT&T	GTE[1]	RCA[2]	ASC	WU[3]
36MHz					
PROTECTED	1,800	1,320[4] 1,800 2,100	1,350 1,650 1,800	1,920 1,950	2,070 2,760
PROTECTED/ PREEMPTIBLE	1,500	1,260 1,470			
UNPROTECTED/ NONPREEMPTIBLE		1,344 1,575	950 1,225 1,300		1,152 1,794
PREEMPTIBLE	900	720 1,050	515 800 750		910 1,380
72MHz		C-BAND	KU-BAND		
PROTECTED		3,120 3,840	2,640 4,200		
UNPROTECTED/ NONPREEMPTIBLE		2,340 2,880	1,980 3,150		
PROTECTED/ PREEMPTIBLE		2,184 2,688	1,848 2,946		
PREEMPTIBLE		1,560 1,920	1,320 2,100		

1 RATE VARIES FROM ORIGINAL SERVICE (18 MONTHS)-HIGHER RATE-TO EXTENDED SERVICE (36 MONTHS)-LOWER RATE.
2 THE FIRST RATE WAS CHARGED IN 1981 THE SECOND IN 1984.
3 LOWER RATE IS MONTH TO MONTH, HIGHER IS FIXED TERM SERVICE.
4 SEVEN YEAR SERVICE IS LOWEST RATE.

2.2 Review of Financial Performance Measures

Investment in communications satellite business ventures requires large up-front investment with significant returns likely to be forthcoming typically five or more years after initial investments. The commitment of significant resources for returns that may occur in the distant future requires careful planning and substantial analysis.

In general, the financial planning is concerned with the development of financial performance measure such as after-tax profit, cash flow, return on assets, return on sales, return on investment (discounted), payback period, net present value and quantitative measures of risk.[48,50] A number of these measures are defined in Figures 2.2 and 2.3.



$$\text{AFTER TAX PROFIT}_t = \left[1 - \frac{\text{TAX RATE}}{100}\right] \times \left[\text{REVENUE}_t - \sum \text{EXPENSES}_t - \text{DEPRECIATION}_t\right]$$

$$\text{CASH FLOW}_t = \text{AFTER TAX PROFIT}_t + \text{DEPRECIATION}_t - \text{CAPITAL EXPENDITURES}_t \pm \text{CHANGE IN BALANCE SHEET ITEMS}_t$$

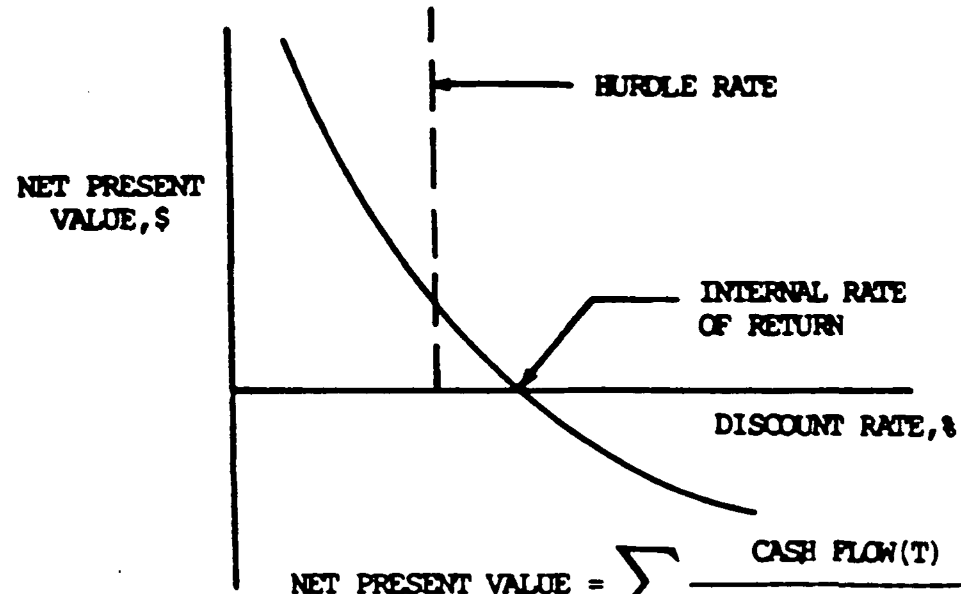
$$\text{INDEBTEDNESS} = -\sum_{k=1}^{t} \text{CASH FLOW}_k$$

FIGURE 2.2 DEFINITION OF ANNUAL AFTER-TAX PROFIT, CASH FLOW, INDEBTEDNESS AND PAYBACK PERIOD

After-tax profit is the difference between revenues and expenses, carry-forward losses and tax credits. Depreciation is an allowed expense which accounts for the wearing out of capital assets. Cash flow indicates the flow of funds through the business venture including after-tax profit, depreciation, capital expenditures and the change in balance sheet items such as accounts receivable and inventory. Indebtedness is the negative of the cumulative cash flow to any point in time. When indebtedness is positive, cash outflows have exceeded cash inflows. The peak of the indebtedness curve indicates the maximum funding requirement of the business venture. The point in time at which the indebtedness passes through zero is the payback period and indicates the time it takes to recoup the investment.

Return on assets is the after-tax profit divided by the book value of total assets. Book value is the value of the original capital expenditures less accumulated depreciation. Assets include capital items as well as cash, receivables and inventory. Return on sales is the after-tax profit divided by the annual revenue.

The net present value (NPV) is the summation of the stream of cash flows discounted to the present where the discount rate is the cost of capital (some firms utilize a risk adjusted rate of return or hurdle rate). The discounted return on investment, ROI, or the internal rate of return, is the value of the discount rate that yields a present value of zero. In other words, the ROI is the rate of return at which the time adjusted value of cash outflows is equal to the time adjusted value of cash



$$\text{NET PRESENT VALUE} = \sum_{T} \frac{\text{CASH FLOW(T)}}{(1 + \text{DISCOUNT RATE})^{T}}$$

INTERNAL RATE OF RETURN = DISCOUNT RATE SUCH THAT PRESENT VALUE = 0.

FIGURE 2.3 DEFINITION OF NET PRESENT VALUE AND INTERNAL RATE OF RETURN

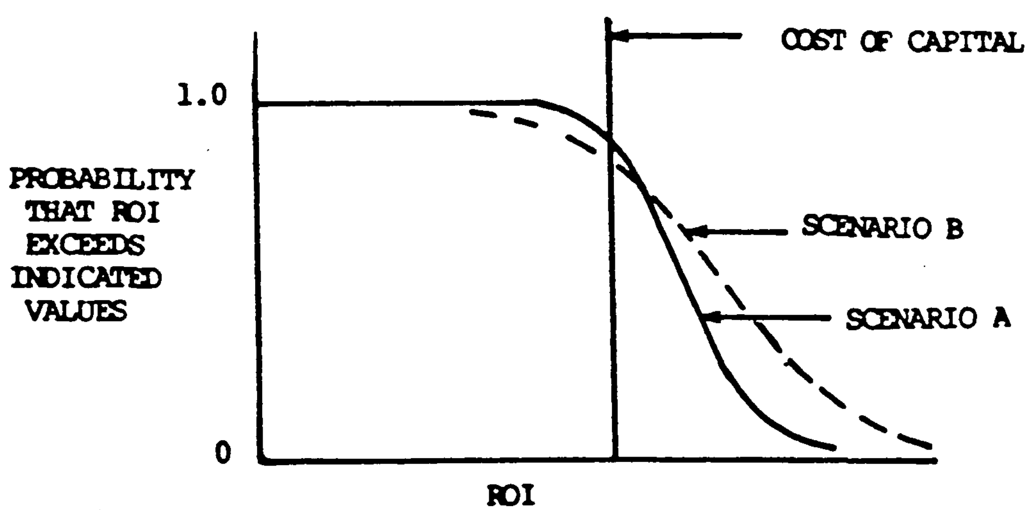


FIGURE 2.4 RISK PROFILES OF ROI

inflows. If the ROI exceeds the cost of capital or hurdle rate then it is desirable to persue the business venture.

There exist many areas of uncertainty; performance, cost, market and schedule. These combined with reliability considerations (both satellite and transportation system) result in risk where risk is defined as the perceived variability associated with the financial performance measures. A convenient way of illustrating risk is in the form of "risk profiles", [48,50] as illustrated in Figure 2.4. The risk profiles indicate the chance that a performance measure such as ROI will exceed different values. It is the function of the DOMSAT II Model (Section 2.3) to convert the various quantitative uncertainty estimates and the effects of unreliability (in the form of random and wearout failures) into the risk profiles associated with the business venture.[48-50] It is through the quantitative consideration of uncertainty, unreliability and resulting risk that differences can be observed between the use of satellites based upon current technology and those satellites configured as a result of NASA spacecraft technology programs.

Figure 2.5 illustrates risk profiles of present value of cash flow for the same business scenario (with unreliability considered but with all uncertainties set to zero - i.e., the certainty scenario) but with on-orbit propulsion system life of 8 and 12 years. Increasing the life from 8 to 12 years (all other factors remaining constant) increases the expected (because the risk profiles are symmetric normal distributions, the 50 percent and expected values are the same) net present value of the

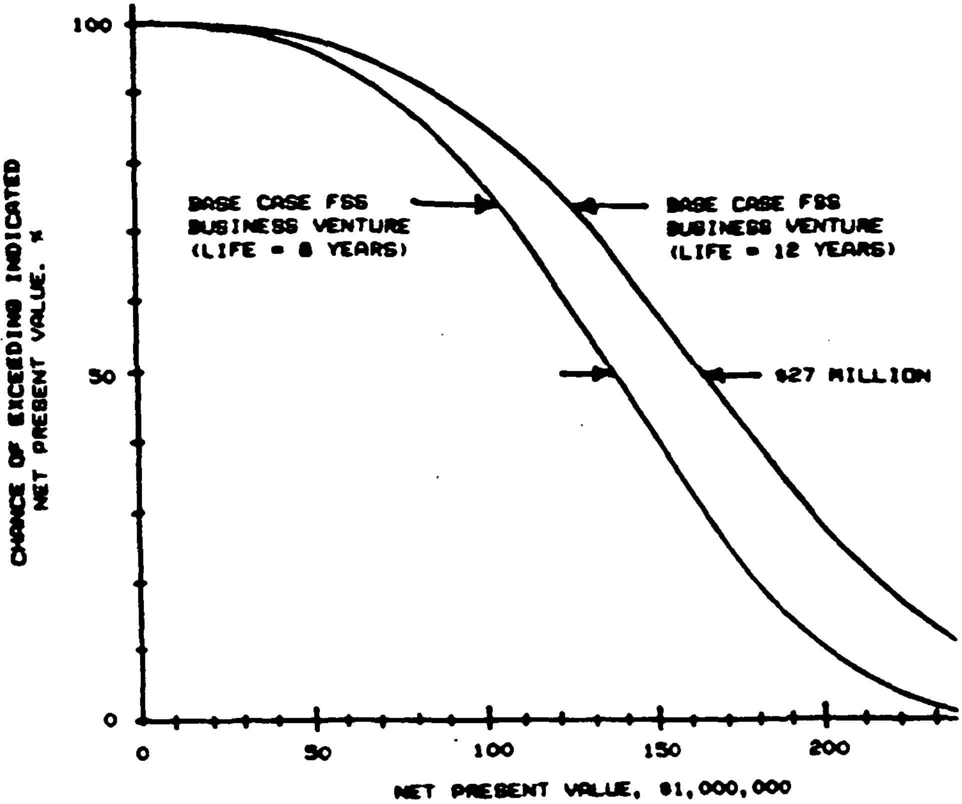


FIGURE 2.5 PRESENT VALUE RISK PROFILES OF A TYPICAL FSS BUSINESS VENTURE AND THE SAME BUSINESS WITH ON-ORBIT PROPULSION SYSTEM LIFE INCREASED FROM 8 TO 12 YEARS (CERTAINTY SCENARIO)

business venture by $27 million. If this were the only business venture to utilize the improved on-orbit propulsion system then (expected) expenditures of less than $27 million to create the technology would be reasonable. These risk profiles are combined and replotted in Figure 2.6 indicating the chance that the incremental net present value will exceed different levels or the value of the new technology to the business venture will exceed different levels.

Generally, many alternatives can be identified (this will be elaborated upon in following paragraphs) from the application of the same and different technologies and must be compared for the selection of the best one. The problems of comparison are eased somewhat by the fact that the probability distributions of the

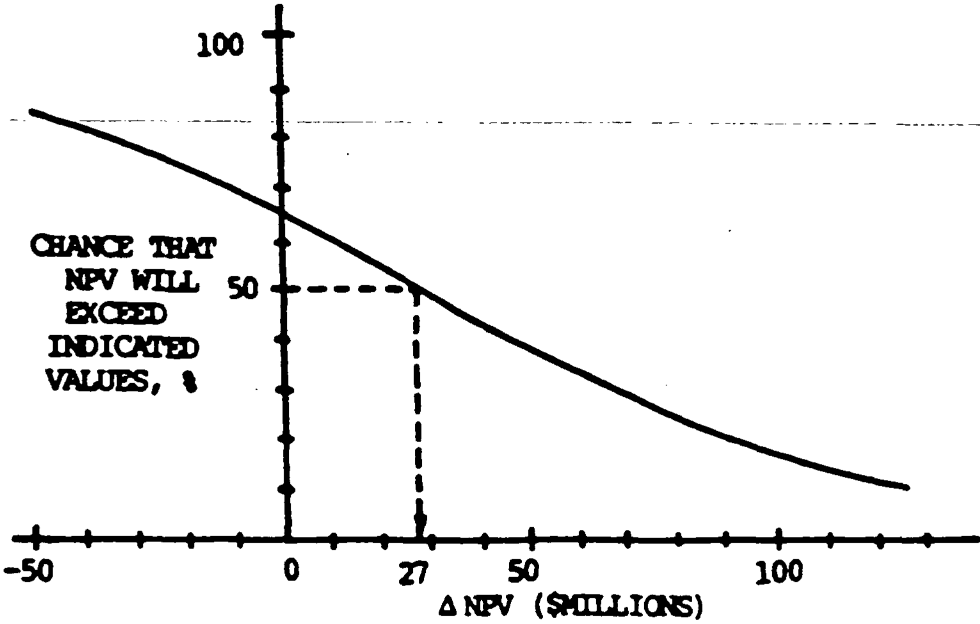


FIGURE 2.6 CHANCE THAT THE INCREMENTAL NET PRESENT VALUE (NPV) WILL EXCEED DIFFERENT LEVELS

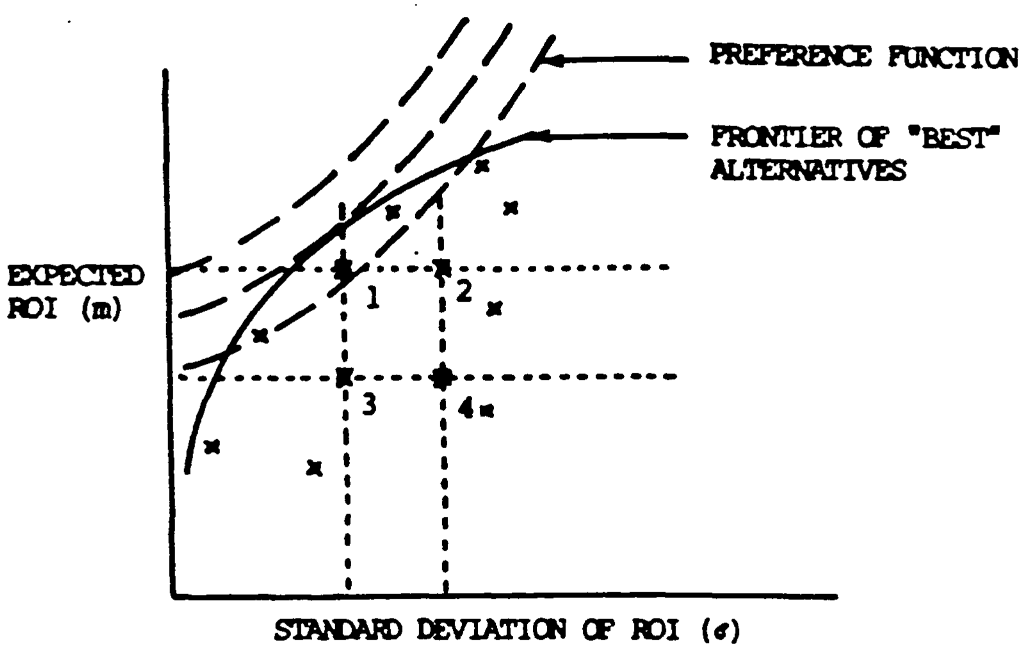


FIGURE 2.7 GENERAL PROBLEM OF DECISION MAKING UNDER UNCERTAINTY

present value of cash flows, return on investment, ROI, and other financial performance measures, are usually very near normal. Thus, the distributions can be fully characterized by their mean, m, and standard deviation, σ , and each alternative can be represented by the point on the m-σ plane. An example is illustrated in Figure 2.7 (in terms of ROI). Here, alternatives 1 and 3 have the same level of risk (i.e., σ 1 equals σ 3) but the expected ROI of alternative 1 is greater than that of alternative 3. Therefore, alternative 1 is preferable to alternative 3. In a similar manner it can be argued that alternative 2 is preferable to alternative 4. Also in a similar manner, alternative 1 is preferable to alternative 2 since both have the same expected ROI but alternative 2 is riskier. This process can be continued with all alternatives being considered. In the limit it can be seen that a frontier of "best" alternatives can be established. Each of the points, or alternatives, represented by the frontier are different in the respect that the risk and the expected ROI are different. The selection of the specific best alternative depends upon the decision maker's risk judgement. That is, the decision maker must decide what the tradeoff is between an increase in expected ROI and an accompanying increase in risk. Hypothetical tradeoffs in the form of a preference function (that is, all points on the preference function are of equal value to the decision maker) indicated by the dashed line in Figure 2.7. The point of tangency of this function with the frontier of best alternatives provides the alternative with the maximum value to the decision maker.

As will be seen, the selection of the best alternative is important in evaluating and comparing the impact of alternative spacecraft technology programs. The considered NASA technology programs (i.e., ion-thrusters and Gallium Arsenide solar cells) have the ability of reducing overall spacecraft mass without altering the performance attributes of the spacecraft. The mass reduction can be taken with the result that transportation charges may be reduced leading to an increase in expected ROI (through cost reduction) with little or no change in risk. On the otherhand, the mass may be put back in a number of different ways, each of which alters spacecraft attributes such as on-orbit propulsion system life, number of active transponders, number of spare transponders, etc. This is illustrated hypothetically in Figure 2.8 where the possible alternative spacecraft configurations (i.e., use of mass savings resulting from the introduction of the new technology) are indicated by points in the m-σ plot of the resulting ROI of the communications satellite business venture. For example, a considerable increase in expected ROI, with an accompanying increase in risk, may result from introducing an ion propulsion system with sufficient propellant to extend satellite wearout life but with a perceived reduction in mean-time-to-failure. Note that changes are all relative to the base case, which is the business venture performance (m and σ) in the absence of the technology programs.

The best use of the mass requires the establishment of the preference curve or risk aversion attitudes as described in Figure 2.7. With the risk aversion attitudes indicated by the

dashed lines in Figure 2.8, alternative D offers the best use of the mass savings and therefore represents the maximum value of the technology program when the results of the program are used in the postulated business scenario. When alternative technology programs are to be compared, the comparison must use the maximum values of each of the technologies as illustrated in Figure 2.9. Here T2 represents case D in Figure 2.8. From Figure 2.9, the choice is between technology 1 (T1) and 2 (T2) both of which offer approximately the same value. It should be noted that both the expected ROI and risk of technology 1 exceed those of technology 2.

2.3 Overview of the DOMSAT II Model

Based upon discussions with the carriers, a stochastic financial simulation model was developed by Princeton Synergetics, Inc. for NASA's LeRC. The DOMSAT II Model allows the impact of S/C technology programs to be evaluated for a broad range of communications satellite business ventures providing a multiplicity of communications services. The Model allows the results of the technology programs to be evaluated in terms of their impact on the financial performance of typical communications satellite business ventures.

The DOMSAT II Model is currently operational on the IBM PC with the input data provided via a user friendly LOTUS 123 system. The mathematical computations are performed in FORTRAN. The Model has been used to assess the impact of LeRC on-orbit propulsion and spacecraft power technology programs on both FSS and DBS business ventures using both spin and three-axis

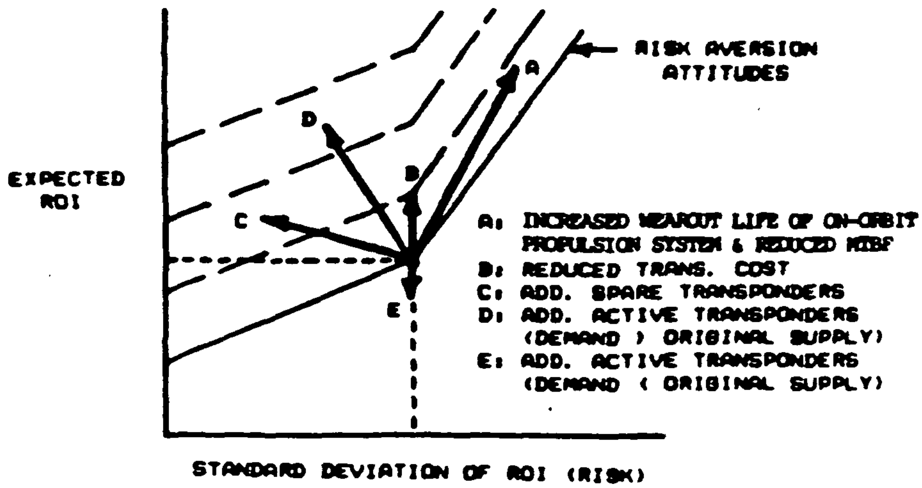


FIGURE 2.8 ASSESSMENT OF THE BEST USE OF MASS SAVINGS FOR A PARTICULAR TECHNOLOGY PROGRAM

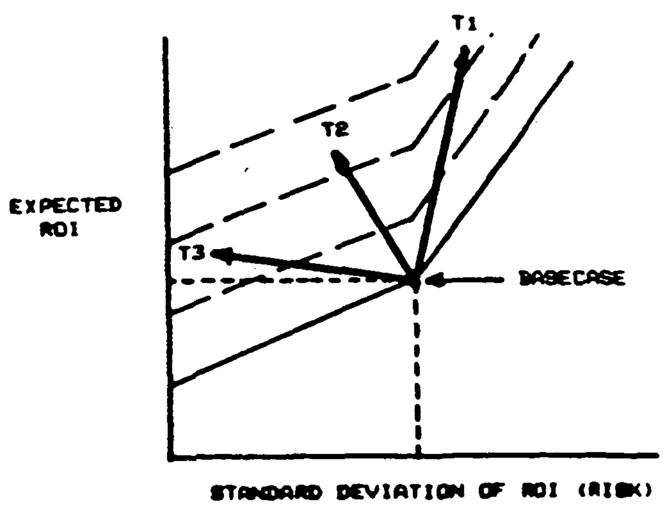


FIGURE 2.9 COMPARISON OF TECHNOLOGY PROGRAMS

stabilized spacecraft. The Model is described in detail in Appendix A with user and programmer documentation provided in Appendix B.

The methodology developed allows a broad range of fixed satellite services and direct broadcast communication satellite business scenarios to be analyzed through the use of the DOMSAT II financial simulation model. The Model allows a broad range of communications satellite business ventures to be simulated explititly and quantitatively taking into account uncertainty, unreliability and resulting risk. The objective is to assess the impact of NASA spacecraft technology programs (for example, on-orbit propulsion and power programs) upon commercial communications satellite business ventures by planning typical business ventures utilizing satellites without and with the technology being considered for development. The value of the technology program is then related to the changes in financial or economic performance measures which then provides insights into the likelihood that the technology will be utilized by the business ventures.

The Model provides the means for evaluating the financial impacts of S/C technology programs, space transportation programs and related policies, on private sector communications satellite business ventures. It specifically allows for the consideration of hybrid (i.e., C- and Ku-band) satellite configurations. This is accomplished by reconfiguring S/C taking into account the anticipated results of S/C technology programs. The resulting S/C configurations are communicated to the DOMSAT II Model through specific estimates of cost, performance and reliability.

These estimates are then combined with a business scenario (i.e., number of satellites as a function of time, number and type of transponders, demand for transponders by type of service provided, pricing, price elasticity, launch system scenario as a function of time, likely launch time delays, transfer time from LEO to GEO, cost of insurance, satellite control operations expense, G&A expense, etc.) to establish annual profit (loss), annual cash flow, cumulative cash flow, ROA, payback period, and ROI. The financial performance measures are all described by probability distributions (i.e., risk profiles) since cost uncertainties (i.e., uncertainty profiles) and subsystem reliability are considered.

The impact of S/C technology programs can be assessed in terms of the differences that result in financial performance measures which are the result of differences in S/C performance and cost attributes resulting from the S/C technology programs and new services made possible by the technology programs. Two analyses are necessary for assessing the financial impacts: one analysis based upon a satellite configuration in the absence of the S/C technology program (i.e., the base case), and a second analysis based upon a satellite configuration incorporating the assumed results of the S/C technology program. The difference in the financial results is therefore assumed to be directly attributable to the C/C technology program.

The establishment of a business scenario consists of specifying the following information (a typical data base used in the analysis of a FSS business venture is presented in appendix B):

* number of years in the business plan
* maximum number of operational satellites
* desired launch schedule
* possible launch delays
* time to transfer from LEO to GEO
* number of narrow-band transponder groups/satellite
* number of wide-band transponder groups/satellite
* number of transponders per narrow-band group
* number of transponders per wide-band group
* number of spare transponders per narrow-band group
* number of spare transponders per wide-band group
* transponder reliability characteristics (mean time to failure, expected wearout life, variability of wearout life)
* S/C support subsystem (up to 5) reliability characteristics
* types of communications services provided (protected, protected/preemptible, unprotected, and preemptible)
* tariffs per narrow and wide-band transponders for each type of communications service
* annual demand for narrow- and wide-band transponders in terms of type of service
* relaunch threshold in terms of number of operational transponders
* annual cost of S/C operations
* annual G&A expense (fixed and variable)
* annual R&D expense (fixed and variable)
* other annual expenses (fixed and variable)
* insurance cost
* S/C cost spreading
* S/C unit recurring cost

* S/C nonrecurring cost
* S/C unit recurring cost learning rate
* launch cost
* launch scenario as a function of time (described in terms of the probability of success of each of the major steps in the launch sequence)
* depreciation lives
* interest rates
* tax related data
* discount rates
* balance sheet related data.

Many of the above variables are considered as uncertainty variables requiring the specification of the range of uncertainty and the form of the uncertainty.

The Model allows uncertainty and unreliability to be considered explititly and quantitatively. This is absolutely necessary when comparing programs which are specifically aimed at reducing uncertainty and altering reliability both of which effect perceived risk and hence effect investment decisions. To establish the quantitative measures of risk, the Model utilizes Monte Carlo techniques wherein the complete business scenario is repeated a large number of times (typically 1000 or more) each time randomly sampling from the uncertainty profiles and the reliability characteristics which are specified. The results of all the business analyses are saved and appropriate statistics developed. Financial performance measures are summarized in terms of expected values and standard deviations. Typical financial reports are illustrated in Figures 2.10 and 2.11 with

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PROFORMA INCOME STATEMENT ($ THOUSANDS)

	YEAR 1	2	3	4	5
PROTECTED	0.	0.	0.	9889.	64779.
PROTECTED/PREEMPT.	0.	0.	0.	0.	0.
UNPROTECTED/NON-PREEMPT.	0.	0.	0.	0.	0.
PREEMPTIBLE	0.	0.	0.	1352.	3320.
TOTAL REVENUE	0.	0.	0.	11241.	68098.
	0.*	0.*	0.*	4400.*	16029.*
LAUNCH OPERATIONS	0.	0.	0.	1903.	4028.
LAUNCH INSURANCE	0.	0.	0.	796.	1630.
SATELLITE	0.	0.	0.	3380.	6802.
OTHER	0.	416.	1229.	1229.	1229.
DEPRECIATION EXPENSE	0.	416.	1229.	7308.	13689.
S/C CONTROL OPERATIONS	0.	0.	0.	753.	1771.
ENGINEERING EXPENSE	1000.	1000.	1000.	1000.	1406.
RESEARCH & DEVELOPMENT	1000.	1000.	1000.	1000.	1406.
TOTAL OPERATIONS EXPENSE	2000.	2416.	3229.	10061.	18272.
	0.*	20.*	48.*	2610.*	2992.*
GROSS MARGIN ($)	-2000.	-2416.	-3229.	1180.	49826.
	0.*	20.*	48.*	1923.*	14148.*
S/C NONRECURRING COST	16756.	4454.	0.	0.	0.
G & A EXPENSE	500.	500.	500.	1321.	1385.
DEBT SERVICE EXPENSE	0.	1322.	5117.	13305.	20225.
BEFORE TAX PROFIT	-19256.	-8692.	-8846.	-13445.	28215.
INCOME TAX	-6932.	-3129.	-3185.	-4840.	10157.
INVESTMENT TAX CREDIT	0.	499.	976.	6079.	6381.
AFTER TAX PROFIT	-12324.	-5064.	-4686.	-2526.	24439.
	591.*	199.*	634.*	2023.*	7551.*
RETURN ON ASSETS (%)	-4267.	-27.	-5.	-2.	13.
	0.*	30.*	1.*	2.*	4.*
RETURN ON SALES (%)	0.	0.	0.	-13.	34.
	0.*	0.*	0.*	18.*	10.*

* STANDARD DEVIATION

FIGURE 2.10 PSS PROFORMA INCOME STATEMENT

PROFORMA INCOME STATEMENT ($ THOUSANDS)

	YEAR				
	6	7	8	9	10
PROTECTED	82387.	92817.	136146.	138503.	131022.
PROTECTED/PREEMPT.	0.	0.	0.	0.	0.
UNPROTECTED/NON-PREEMPT.	0.	0.	0.	0.	0.
PREEMPTIBLE	6394.	6039.	4035.	2231.	3350.
TOTAL REVENUE	88782.	98855.	140181.	140734.	134372.
	10464. *	8386. *	13416. *	12539. *	12664. *
LAUNCH OPERATIONS	4375.	6343.	6819.	7050.	7326.
LAUNCH INSURANCE	1759.	2467.	2633.	2712.	2805.
SATELLITE	7315.	10044.	10674.	10971.	11314.
OTHER	1488.	1649.	1649.	1649.	1649.
DEPRECIATION EXPENSE	14936.	20503.	21774.	22381.	23094.
S/C CONTROL OPERATIONS	1509.	1977.	2523.	2533.	2553.
ENGINEERING EXPENSE	1777.	1977.	2804.	2815.	2687.
RESEARCH & DEVELOPMENT	1777.	1977.	2804.	2815.	2687.
TOTAL OPERATIONS EXPENSE	20001.	26434.	29905.	30544.	31022.
	1617. *	2962. *	2947. *	3600. *	4504. *
GROSS MARGIN ($)	68781.	72421.	110277.	110191.	103350.
	9903. *	8871. *	13836. *	14304. *	15346. *
S/C NONRECURRING COST	0.	0.	0.	0.	0.
G & A EXPENSE	1210.	1291.	1341.	1344.	1441.
DEBT SERVICE EXPENSE	21529.	20471.	17079.	9294.	-215.
BEFORE TAX PROFIT	46041.	50660.	91857.	99552.	102124.
INCOME TAX	16575.	18238.	33068.	35839.	36765.
INVESTMENT TAX CREDIT	1299.	5598.	1272.	607.	713.
AFTER TAX PROFIT	30766.	38021.	60060.	64320.	66072.
	5926. *	6161. *	9336. *	11157. *	12725. *
RETURN ON ASSETS (%)	15.	18.	30.	35.	40.
	3. *	4. *	6. *	8. *	11. *
RETURN ON SALES (%)	34.	38.	43.	45.	49.
	6. *	4. *	5. *	6. *	7. *

* STANDARD DEVIATION

FIGURE 2.10 FSS PROFORMA INCOME STATEMENT (CONTINUED)

CASH FLOW PROJECTION ($ THOUSANDS)

	YEAR				
	1	2	3	4	5
AFTER TAX PROFIT	0.	0.	0.	0.	24540.
INCREASE IN PAYABLES	1598.	1489.	3203.	388.	78.
DECREASE IN RECEIVABLES	0.	0.	0.	0.	2.
DECREASE IN CASH	0.	12.	0.	23.	215.
DEPRECIATION	0.	416.	1229.	7308.	13689.
TOTAL CASH INFLOW	1598.	1916.	4432.	7718.	38525.
LOSS	12324.	5064.	4686.	2526.	101.
DECREASE IN PAYABLES	0.	64.	0.	126.	1189.
INCREASE IN RECEIVABLES	0.	0.	0.	1877.	9438.
INCREASE IN CASH	289.	269.	579.	70.	14.
CAPITAL EXPENDITURES	0.	28148.	67397.	60793.	38588.
TOTAL CASH OUTFLOW	12612.	33544.	72661.	65392.	49390.
NET CASH FLOW	-11014.	-31628.	-68229.	-57674.	-10865.
	528.*	8243.*	9908.*	11262.*	18110.*
INDEBTEDNESS	11014.	42642.	110872.	168545.	179411.
	528.*	8252.*	17582.*	15468.*	15185.*

	1	2	3	4	5
DISCOUNT RATE (%)	10.	15.	20.	25.	40.
NET PRESENT VALUE "A"	86510.	21054.	-13801.	-32055.	-46006.
NET PRESENT VALUE "B"	192851.	63132.	23965.	9977.	1017.
NET PRESENT VALUE	279361.	84186.	10164.	-22078.	-44983.
	83052.*	44304.*	27649.*	18769.*	7874.*

* STANDARD DEVIATION

FIGURE 2.11 FSS CASH FLOW PROJECTION

detailed launch and S/C purchase statistics illustrated in Figures 2.12 and 2.13. It should be noted that the financial documents contain expected values except for those items which are noted with * indicating standard deviations. The particular form of the financial statements is the result of discussions with several carriers.

The Model develops many financial performance measures including after-tax profit, annual cash flow, cumulative cash flow, return on sales, return on assets, payback period, and net present value. Expected values and standard deviations are established for all of these. The net present value is established at a number of discount rates so that the internal rate of return (or discounted return on investment - ROI) can easily be established.

The Model consists basically of two parts. The first, utilizing the desired schedule of events, demand for communications services, the satellite configuration, specified launch scenario and reliability characteristics, establishes the specific timing and number of events and their costs. The availability of transponders (taking into account failures, sparing concepts and services offered) is matched against launch decision criteria in order to establish the schedule for replacement launches and the timing of additional capital expenditures for replacement satellites and launches. The timing and cost information is then passed to the second part of the Model which performs the financial computations and establishes values of the financial performance measures.

The Model is implemented such that certainty conditions can

PROBABILITY OF ANNUAL LAUNCH ATTEMPTS

LAUNCH ATTEMPTS	PROBABILITY OF INDICATED QUANTITY (PERCENT)							
10	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
2	0	0	0	0	14	1	7	2
1	0	0	0	100	86	17	93	21
0	100	100	100	0	0	82	0	77
YEAR	1	2	3	4	5	6	7	8
AVERAGE VALUE	.00	.00	.00	1.00	1.14	.19	1.08	.26
STANDARD DEVIATION	.00	.00	.00	.00	.34	.41	.27	.49

PROBABILITY OF ANNUAL LAUNCH ATTEMPTS

LAUNCH ATTEMPTS	PROBABILITY OF INDICATED QUANTITY (PERCENT)						
10	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
3	0	0	0	0	1	1	0
2	1	1	1	3	16	14	1
1	11	13	13	25	54	48	9
0	88	86	86	72	29	36	90
YEAR	9	10	11	12	13	14	15
AVERAGE VALUE	.13	.15	.15	.31	.90	.82	.12
STANDARD DEVIATION	.35	.39	.37	.53	.70	.75	.35

FIGURE 2.12 FSS LAUNCH STATISTICS

PROBABILITY OF ANNUAL SPACECRAFT PURCHASES

NUMBER OF SPACECRAFT	PROBABILITY OF INDICATED QUANTITY (PERCENT)							
10	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
2	0	0	0	0	12	1	6	2
1	0	0	0	94	82	17	87	20
0	100	100	100	6	5	83	7	78
YEAR	1	2	3	4	5	6	7	8
AVERAGE VALUE	.00	.00	.00	.94	1.07	.18	1.00	.24
STANDARD DEVIATION	.00	.00	.00	.24	.42	.40	.38	.48

PROBABILITY OF ANNUAL SPACECRAFT PURCHASES

NUMBER OF SPACECRAFT	PROBABILITY OF INDICATED QUANTITY (PERCENT)						
10	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
3	0	0	0	0	1	1	0
2	1	1	1	2	14	13	1
1	11	12	13	24	53	48	9
0	89	87	87	74	32	38	90
YEAR	9	10	11	12	13	14	15
AVERAGE VALUE	.12	.14	.14	.29	.83	.77	.11
STANDARD DEVIATION	.34	.38	.36	.51	.68	.72	.34

FIGURE 2.13 FSS SPACECRAFT STATISTICS

be easily analyzed as well as the uncertainty situations. For example, the number of desired runs is an input parameter and can be set to one when all ranges of uncertainty are set to zero (i.e., minimum and maximum values are set equal). A user friendly system has been developed for entering this data into the Model and is described in Appendix B.

2.4 Cost Estimation - The RCA PRICE Model

The analysis of communications satellite business ventures requires the specification of satellite recurring and nonrecurring costs. The RCA PRICE Model, a set of cost estimating relationships and associated data base, was used to establish the recurring and nonrecurring costs for the FSS and DBS base case satellites as well as comparable costs for the spacecraft utilizing the ion-thruster and Gallium Arsenide solar cells as per the NASA specified technology programs. These "new" technology configurations included major redesigns so as to make most efficient use of the technology improvements.

The RCA PRICE Model was used for all cost estimates with the exception of the launch costs. These were established using the Space Shuttle pricing formula that relates price to mass or length. The cost estimation is described in Section 5.4.

The DOMSAT II Model was configured so as to simulate a broad range of communications satellite business ventures. As with all models that attempt to simulate the real world there are limitations to the scope of the business ventures that may be reasonably simulated. Even for those that may be simulated the level of detail considered is limited. The following paragraphs indicate the range of business scenarios that may be simulated and describe in general terms the business scenarios considered for assessing the impact of the specified NASA technology programs. The specifics of the considered scenarios are described in Section 6 and Appendix C.

Business scenarios are described in terms of market, technology, financial and scheduling considerations. In general, the market considerations include the specification of the services to be provided, the demand for the services, pricing of services and price elasticities (cross-elasticities are not considered). The technology considerations include the specification of the number and type of transponders and their arrangement (including sparing), and transponder and other S/C subsystem reliability characteristics. Technology considerations also include the specification of the launch scenario in terms of the probability of success of performing each of the major steps in the launch sequence. Scheduling considerations include desired launch times for initial launches and likely rescheduling launch delays. The financial considerations include the

specification of launch, insurance, S/C nonrecurring and recurring costs and associated cost spreading functions. It also includes the specification of tax related data, interest rates, discount rates and various expense and balance sheet data. The data requirements are summarized in Section 2 and described in detail in Appendix B.

The establishment of a business scenario starts by specifying the maximum number of operational satellites that will be included in the business system during the planning horizon and the desired launch schedule for each. The Model establishes when each of these satellites is actually launched and when each fails and is to be replaced. Whenever a launch is attempted the Model establishes whether or not it is successful. If the launch is unsuccessful a relaunch will be scheduled based upon possible launch delays (the launch delay may be treated as an uncertainty variable). The time to transfer from LEO to GEO (including the time required for on-orbit testing) must also be specified. Since additional transponder failures (those already in orbit on other S/C) may occur during this time, long transfer and testing times may have an impact on revenue.

The Model allows hybrid S/C to be considered as well as S/C operating exclusively in a single frequency band. This is accomplished by considering two classes (actually the classes may be the same) of transponders - each class may contain a number of groups of transponders containing a number of operational and spare transponders. The number of classes (one or two), number of groups per class and number of active and spare transponders per group must be specified. All satellites in the business

system are assumed to be identical. The classes of transponders are referred to as narrow- and wide-band transponders - it must be emphasized that the Model does not directly consider the bandwidth characteristics of the transponders but only the number of actual and spare transponders and their reliability characteristics. The effects of bandwidth differences are accounted for in the specified tariffs for the narrow- and wide-band transponders. Thus, the number of groups, number of active and spare transponders per group and transponder mean-time-to-failure and expected and variability of wearout life must be specified for both the narrow- and wide-band classes. Since the survivability of transponders is effected by the S/C support subsystems, their reliability characteristics must also be specified.

As previously described, four types of communications services may be provided. The specific services to be provided by the business must be identified and the demand for these services specified for each of the operational satellites as a function of time. The demand is specified in terms of number of revenue generating transponders each year for both the narrow- and wide-band transponders. The demand may be considered as an uncertainty variable. Also to be specified are the anticipated tariffs for each type of transponder for each type of service (also an uncertainty variable). This data must be provided annually. Price elasticities need also be specified.

Since two different types of transponders (having different revenue generation capability) may be considered it is necessary

to specify a relaunch threshold in terms of both the operational narrow- and wide-band transponders. When this threshold is crossed another satellite (i.e., a replacement satellite) launch will be attempted.

A launch scenario must be specified for each year of the business planning horizon. The specification of the launch scenario is accomplished by providing estimates of the probability of success for each of the major steps in the launch sequence. Thus, both Space Shuttle (i.e., reusable) and expendable transportation systems may be specified by setting appropriate probabilities of success to zero or non-zero values. Different launch scenarios may be specified for each year of the business plan.

Prior to the launch of the first satellite, the Model automatically purchases a spare S/C and places it into inventory. This S/C is then used for the next launch and another S/C becomes the spare in ground inventory.

Insurance may be considered for launch and satellite cost as a percentage of these costs. This percentage (may be considered as an uncertainty variable) must be specified. If no insurance is to be taken (i.e., self-insurance), this must be explicitly stated.

Annual cost of S/C operations, G&A expense (both fixed and variable), R&D expense (both fixed and variable), and other annual expenses (both fixed and variable) must be specified. These may be treated as uncertainty variables. S/C unit recurring cost learning rate must also be specified. S/C unit recurring and nonrecurring and launch cost must be specified and

may be treated as uncertainty variables. The S/C costs are specified for first unit and learning effects are used to establish other costs. Cost spreading functions (percentage of expenditures made each year) must be specified for S/C unit recurring and nonrecurring cost and launch cost. Launch costs must be specified each year taking into account S/C attributes and launch scenario.

Finally, other business related factors such as depreciation lives, interest rates, tax related data, discount rates and balance sheet related data must be specified to complete the definition of the business venture.

The above data (provided as per the details in Appendix B) completely specifies a business scenario. Two base case business scenarios were developed (in terms of the above data); one for an FSS business venture and the other for a DBS business venture. Spacecraft technology programs were identified by NASA together with their likely outcomes. These likely outcomes were used to specify the new technology that would be available for incorporation into the base case S/C (see Section 4). The base case S/C were reconfigured using the new technology so as to maximize the value of the technology to the business venture (see Section 5). The reconfiguration of the S/C, in general, resulted in mass reductions that were put back so as to alter the attributes of the S/C and increase capability. The mass savings were used to extend satellite life and to increase the number of available transponders. It was determined that for the business scenarios considered it was of greater value to increase

satellite capability than to use the mass savings to achieve transportation cost savings (see Section 6). Thus two business scenarios were defined into which were placed the base case S/C (i.e, without the technology that would be developed as a result of the specified NASA technology programs) and new technology S/C incorporating the anticipated results of the NASA technology programs. The financial value of the business scenarios without and with the new technology satellites was established - the differences being the value of the technology programs to the specific business scenarios evaluated. Specific results are presented in Section 6 for each of the considered business scenarios and extrapolations to satellite markets are presented in Section 7.

4.1 Introduction

Two technology improvements were chosen for consideration. These were judged to be NASA programs which could most significantly impact the utility of communications satellites in the time frame of interest. Ion propulsion for North-South Stationkeeping (NSSK) and Gallium Arsenide (GaAs) solar cells were selected as the two technology areas to be analyzed for application in the 1990 time frame. The assessment of the U.S. technologies is largely based on information provided by NASA. In addition, foreign technology in associated areas which would compete with applied NASA technologies was assessed. Specifically, European and Japanese programs in electric propulsion and solar cell development were investigated.

The two satellites used as models represent the two types of services which will be available from communications satellites, i.e. fixed services (point to point) and direct broadcast (to home receivers). These are compared with and without the improved technology assumed to result from the NASA programs. To further account for different satellite design philosophies, a spinning configuration and a three-axis stabilized configuration were considered. Both spacecraft represent current state-of-the-art satellite designs and, in fact, similar satellites are now being built for specific customers. In both cases those customers are commercial corporations within the United States.

The two technologies selected for this study, inert gas ion propulsion and Gallium Arsenide planar solar arrays, are

components of the NASA Lewis Research Center Technology Program. Because of the limited time and scope of this study it was not possible to delve into the full depth of detail associated with these technologies. However, an attempt was made to extract the essence of performance improvements required to assess the impact of these technologies on the selected spacecraft. The results are representative of the improvements possible with the inclusion of the new technologies.

4.2 NASA Technology

4.2.1 Ion Propulsion for North-South Stationkeeping (NSSK)

Electric propulsion is an advanced form of space propulsion that makes use of electrical energy to accelerate and expel an ionized propellant at a relatively high exhaust velocity. In contrast to chemical propulsion, the exhaust velocity is a variable that can be controlled in the design and operation of the electric thrusters. There are two generic types of electric thrusters categorized as electrostatic and electromagnetic, according to the mechanism used for accelerating the propellant. In this study only the electrostatic type of propulsion, otherwise known as ion propulsion, was considered and applied specifically to a particular function, that is north-south stationkeeping. This is the application that promises the most important savings in spacecraft mass.

The particular electrostatic ion-thrusters of interest here are sometimes known as the electron bombardment type. They usually use a gaseous propellant which is typically mercury vapor, xenon, or argon. These gases are ionized by electron

impact in a discharge chamber to form a neutral plasma. A relatively high voltage of up to 5000 volts must be applied to the accelerating electrodes in order to extract ions from the discharge plasma and accelerate them to high velocity; thus the exhaust is an ion beam. In order for such a device to be used effectively as a thruster, electrons must be injected into the ion beam in equal numbers in order to neutralize the exhaust. The use of these high voltage accelerating electrodes and associated heaters and discharge power requirements make a significant impact on the spacecraft power system.

The inert gas ion-thruster is the technology of interest. This represents the latest technology with respect to the development of electrostatic thrusters and is the program currently under development by the NASA Lewis Research Center. This technology is taken and applied to the two baseline spacecraft and the impact on the utilization and performance of the spacecraft is developed.

1990 technology is assumed in all cases for the NSSK. The ion-thruster spacecraft designs lead to an 8-cm diameter thruster with a thrust level of 8.6 mN. An eight year mission life for the fixed sources and a seven year mission life the for direct broadcast satellites lead to a propellant mass of Xenon of 9.4 Kg for the former and 8.2 Kg for the latter.

A typical ion thruster subsystem has major components consisting of the ion-thruster, the power processor, and the propellant tank and float control. The specific impulse derived, based on various formulae and constraints on the spacecraft, was found to be 2,926 seconds with a power-to-thrust-ratio of 32.2.

The duty cycle for operation is assumed to be three hours per day, every day for the mission. This will counter the acceleration due to lunar and solar attraction. The details of the system are given in Section 5.0.

4.2.2 Gallium Arsenide (GaAs) Planar Solar Arrays

In the last 30 years, photovoltaic technology has made impressive advances in the U.S. space program. Performance has steadily improved, durability and reliability have been refined and costs held stable. For the past five years, the NASA program has emphasized the laying of a foundation for high capacity, earth orbital photovoltaic power systems. Such a technology program offers the possibility of significantly reducing the mass of the power systems of geosynchronous communications satellites. With power system mass equaling payload mass in present technology, there are obvious opportunities to improve spacecraft performance for commercial applications.

Another aspect of geostationary orbital operation results in the need to increase the radiation tolerance of solar cells. Increased tolerance not only increase the end-of-mission (EOM) power which reduces the size and mass of the array, but also flattens the change (degradation) of power with time, which can lead to power system simplification. The NASA photovoltaic program has major targets of increased efficiency, increased radiation tolerance and the use of concentrators in solar and planar arrays with reduced mass and increased performance.

Concentrators have emerged as a cost effective, viable alternative to silicon planar arrays. For example, miniaturized

Gallium Arsenide solar cells with 19 % efficiency at 100 times concentration and 80° C temperature have been demonstrated. The GaAs technology in planar arrays is applied to the spacecraft configurations in order to study enhancemented spacecraft performance due to the introduction of this new solar cell technology.

Lightweight array technology continues to advance and is nearing flight readiness. Lightweight designs with thin cells have successfully passed 4,000 geosynchronous thermal cycles. Thus, there is confidence in a greater than twenty-year durability. Lightweight blankets require lightweight deployment mechanisms, thus, reducing the mass of the mechanisms associated with the solar array drives for a non-spinning spacecraft.

Gallium Arsenide solar cells have well-known advantages over silicon solar cells, making them potential candidates for use in a wide variety of space missions. The availability of these cells will provide new benefits in terms of reduced mission cost and increased mission capability. There are four major advantages associated with the use of Gallium Arsenide solar cells: high-temperature operations, higher efficiency, higher specific power, and increased radiation resistance.

As an indication of the impact that Gallium Arsenide cells could have on commercial space missions, Figure 4.1 illustrates power available in an orbit with 200° C annealing over a period of 10 years. Thus, the impact on the geostationary missions of these anticipated radiation resistant Gallium Arsenide cells, coupled with annealing at 200° C is significant. In fact, the

regulation of power output over the life of a geostationary mission to within 5%, is a possibility.

A common misconception is that Gallium Arsenide cells have a weight disadvantage relative to silicon cells. In fact, conventional space blankets supply more power per unit mass with GaAs than do silicon cells. Table 4.1 presents a comparison of panel weights for silicon arrays using a K7 cell and a GaAs array using 17% standard LPE cells, currently under Air Force development. Both arrays are designed to provide the same power at end of mission (defined as 7 years in geosynchronous orbit). Not only will the total blanket weight be reduced by more than 6% with GaAs but total panel area will be 27% less as well.

The potential for ultra-high specific power with GaAs far exceeds anything achievable with silicon. With the anticipated improvement in efficiency and reduction in mass yet to come, cell specific power approaching 10 kW per kg now appear feasible. Blanket specific powers in excess of 1.5 kW per kg should also be achievable. This blanket specific power includes solar cell blanket mass, mass of the covers and adhesives and cell interconnections. Current space cell blanket specific powers are typically 40 to 80 Watts per kg, a factor of 20 to 40 less than anticipated for future GaAs blankets.

Solar cells intended for space use must withstand many severe environmental challenges. A major concern for geosynchronous missions, for example, is the degradation of cell output caused by charged particle bombardment. Current technology silicon cells will degrade as much as 25% or more over a 10-year life. GaAs cells exhibit a degradation of only about

TABLE 4.1 COMPARISON OF GaAs AND SILICON CELL MASSES*

Subsystem	GaAs	K7
Cell Assembly	40.4 kg	35.7 kg
Adhesive, etc.	5.7	7.8
Substrate	18.9	25.9
	65.0 kg	69.4 kg

*Panel Size Reduction: 27 %

Baseline: 2 X 4 cm GaAs Cell, Same BOL Power as K7 Cell (821 W)

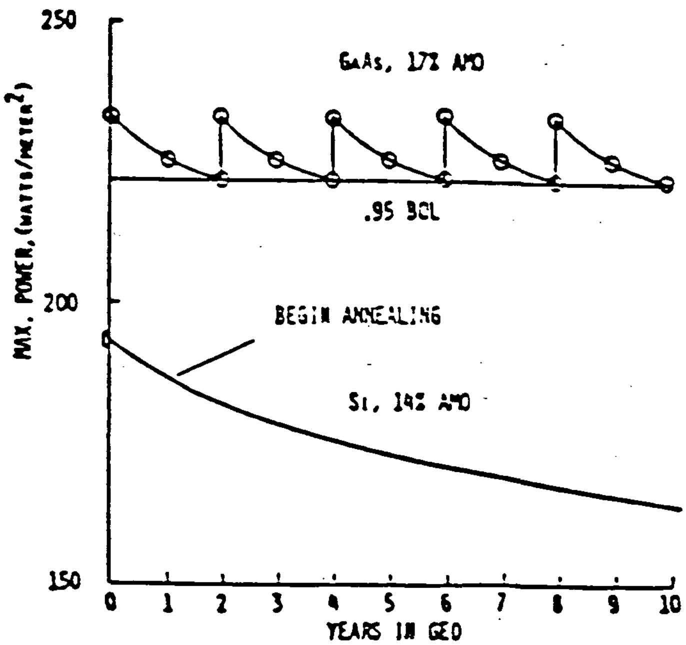

FIGURE 4.1 POWER AVAILABLE IN ORBIT WITH 200° C ANNEALING

15% over the same 10-year period. However, complete radiation resistance is not anticipated for GaAs or silicon. Therefore, restoration to beginning-of-life (BOL) output by some kind of annealing is desirable. In fact, GaAs is amenable to such processes and can be restored to beginning of life output power on a periodic basis. This then reduces or eliminates the overall degradation of power available to the spacecraft.

Mission studies show that for certain mission classes GaAs cells at a cost of $300.00 per watt can be competitive with silicon cells at a cost of $100.00 per watt on a total mission cost basis. Thus, GaAs solar cells do show many technological advantages over silicon solar cells and appear particularly suited for geostationary missions. Power-to-mass-ratios as high as 2.5 kW per kg have been demonstrated. Radiation resistance is already comparable to that achieved in the best silicon cells and annealability surpassing that demonstrated by silicon has been observed. Thus, GaAs solar arrays have been considered for implementation in the 1990 time frame. A conservative 1.5 kW per kg is assumed for the blanket specific power of the solar arrays. Associated improvements have been taken into account in the developed advanced technology spacecraft designs.

4.3 Foreign Technology

4.3.1 Ion Propulsion for NSSK

In Germany

The most extensive development of ion propulsion in the free world outside of the United States has been in Germany. The RIT series of thrusters have been developed to a flight ready status

at the University of Geissen since 1960. [1] RIT stands for Radiofrequency Ion-Thruster and denotes a series of thrusters wherein the gas ionization for the production of ions to be accelerated is accomplished by the absorption of 1 MHz electromagnetic radiation instead of contact ionization or the method used principally in the United States of electron bombardment ionization. A series of thrusters with beam diameters from 4 cm to 35 cm have been tested using mercury as the propellant. The RIT-10 thruster with a 10 cm beam diameter was chosen for industrial development by MBB in 1970 as its thrust level (10 mN) was considered well developed at that time. The RIT-10 thruster was developed for the APEX and H-SAT satellites but both programs were cancelled. [2] The RIT-10 was then developed for the German-French TV-SAT D3 telecommunications satellite but was deleted from the mission due to budgetary considerations. As a result of these development programs, the RIT-10 thruster has been extensively tested over long periods of time. Using mercury as the propellant, the RIT-10 thruster produces 10 mN of thrust with an exhaust velocity of 38 Km/s. Beam current is a maximum of 220 mA and beam voltage is 1.5 KV. The RIT-10 thruster consumes 375 W of power and has been lifetime tested up to 8150 hours.

In 1982, an opportunity to fly the RIT-10 thruster on the European Eureca-I retrievable satellite materialized. The RIT-10 thruster with neutralizer, propellant storage and feed systems and power conditioner and control is designated the RITA-10 system (RIT-10 Assembly). Due to contamination of the exterior of the Eureca-I, which is to be retrieved by the Space Shuttle,

the RIT-10 propellant was changed from mercury to xenon. The RIT-10 thruster originally designed to operate with mercury was found to provide similar performance with xenon as the propellant with a slight increase in required electrical power principally due to the increased energy needed for propellant ionization. [3] Thrust for the RIT-10 thruster utilizing xenon as the propellant is variable from 7 to 14 mN. At a baseline thrust of 10 mN, beam current is 0.156 A, beam voltage is 1,500 V and the specific impulse is 2,450 sec. Mass flow is 0.4 mg/s and total efficiency is between 55% and 60%.

Due to the increasing size of geostationary communications satellites, the RIT-10 is felt to have been outgrown by the satellites it was designed to operate on. Therefore, work was initiated in 1981 to adapt a larger RIT-15 thruster for use with xenon. [4] The RIT-15 thruster with a 15 cm beam diameter was originally designed to use mercury as the propellant but like the RIT-10 thruster was found to work well with xenon. Thrust was measured up to 16.2 mN at a beam current of 0.249 A and a beam voltage of 1,550 V. Mass flow at this thrust value was 0.415 mg/s with an exhaust velocity of 37.2 Km/s. Electrical efficiency was 62.6%, propellant efficiency was 78.3% and total efficiency was 49%. Total power consumed is 617 W with 160 W of the total going to the RF ionization system. Work is continuing on the RIT-15 xenon thruster with a goal of 40 mN of thrust at a beam current of 0.570 A and a mass flow 0.955 mg/s. Associated goals are an exhaust velocity of 42.4 Km/s, a beam voltage of 1,800 V and a total efficiency of 61.6%. The total required electrical power at these conditions would then be 1380 W.

In Japan

Although ion propulsion development in Japan has not been as extensive as in Europe, there has been the opportunity to flight test hardware. The Japanese effort up to this time has been concentrated on a 5-cm diameter mercury ion-thruster utilizing electron bombardment propellant ionization. Two of these thrusters were tested on the ETS-III (Engineering Test Satellite) launched on September 3, 1982. [5] These engines were developed by the National Space Development Agency of Japan. During the flight, measured performance duplicated ground-based test results. Thrust was measured to be 2 mN at a specific impulse of 2,357 seconds. Beam current was 0.030 A and beam voltage was 1,000 V. Mass flow was 0.1 mg/s with a propellant utilization efficiency of up to 75%. The total ion propulsion system including propellant and two thrusters weighed 22 Kg and consumed 100 W of electrical power. One of the thrusters has accumulated 182 hours of operation in space.

A 20 mN class thruster test utilizing xenon as the propellant is planned for ETS-VI to be launched in 1992. [6] Projected performance for this thruster includes a beam diameter of 12 cm, beam current of 0.480 A at the same beam voltage of 1,000 V and a thrust of 25 mN at a specific impulse of 3,400 seconds.

In France

The youngest of the ion propulsion development programs is located in France involving the FEEP program. [1] FEEP stands for Field Emission Electric Propulsion where the ion acceleration

process is not obtained by the usual method of acceleration grids based at high voltages. In FEEP a liquid metal surface is subjected to high electric field causing cusps to form. At the tips of these cusps, the electric field is high enough to spontaneously produce ions which are then accelerated away in a beam providing thrust. The particular design being studied by the French firm SEP has the ions being emitted through narrow (1 micrometer) slits. Performance has been measured in the laboratory to be a thrust of 0.31 mN/cm at a specific impulse of 10,900 seconds. The principal drawbacks to the use of such a system are that liquid metals such as cesium must be used as propellants and that the high specific impulse requires a large amount of electrical power to obtain appreciable thrust levels. Finally, units are still far from flight testing.

4.3.2 Solar Cells [1-5]

Over the past several years, both the Japanese and Europeans have been working steadily and intensively on the development of silicon and Gallium Arsenide solar cells. In Japan, the leaders in this development are Sharp and Mitsubishi. In Europe AEG Telefunken is the principal supplier of cells. However, advanced array structures are being produced by MBB, Fokker, Aerospatiale and British Aerospace.

In Japan, the Sharp Corporation in conjunction with NASDA, the National Aerospace Development Agency of Japan, has been developing ultrathin solar cells which have been qualified for space. These use a 55 micrometer thick silicon wafer. In order to recover the loss of electrical output caused by thinning

substrates, the manufacturing process has been improved recently. Ultrathin cells of size 2 cm x 2 cm which were fabricated by this new process have shown outputs of 72.5 mW. This represents an increase of 1.8 mW over that of the 280 micrometer thick cells fabricated by the conventional method.

Mitsubishi in conjunction with NASDA has developed some Gallium Arsenide cells with higher performance in radiation resistance and energy conversion efficiency as compared to conventional silicon cells. Test results indicate that 2 cm x 2 cm Gallium Arsenide cells have efficiencies ranging from 16.4 to 18.6%. A typical value is 17.5%. This represents an output for this cell of 94.7 mW.

Solar array development in Europe is typified by the activities of Fokker Space Division. Here activities include the construction of complete solar array subassemblies which are supplied to satellite prime contractors. Fokker has attempted to set up a generic solar array design for 3-axis stabilized satellites which provides prime contractors with a number of technical and commercial degrees of freedom. This design allows the spacecraft builder to tune the array properties to their specific requirements without the need for extensive redesign. The array supplies power in the range of 2 to 4 kW at end of life. This design is called the Advanced Rigid Array and consists of a rigid, panel type solar array. A number of panels can be selected (between 3 and 7). This design is capable of achieving or exceeding 30 to 40 W/kg for the complete array subsystem including the satellite sidewall mounted substructures. Table 4.2 summarizes large solar arrays being developed in

Europe. Two of these, the ARA and the L-SAT represent new developments while the others have already been developed. Existing European arrays have considerable growth capabilities.

TABLE 4.2 LARGE SOLAR ARRAYS IN EUROPE

Name	Type	BOL Equinox Power (KW) Tested	Growth	Retraction
GSR	Rigid Panel Fold-out	3	6	-
ULP	Rigid Frame Fold-out	3	10	+
ARA	Rigid Panel Fold-out	(3)	6	-
DORA	Double Roll-out	9	(20?)	+
ST	Double Roll-out	5	10	+
SPOT	Flexible Fold-out	2.6	10-12	-
L-SAT	Flexible Fold-out	4.2	11	-

5. SPACECRAFT CONFIGURATIONS AND COSTS

5.1 Introduction

Two spacecraft configurations were selected as being representative of the communications satellite industry. These two configurations consisted of a fixed services satellite and a direct broadcast satellite. Further considerations included the fundamental question of stabilization technique. Since there are two approaches to this problem (i.e., spin stabilization and three-axis stabilization), it was deemed appropriate to select one of these two satellites as a spinner and one as a non-spinner. Therefore, the fixed services satellite was selected to be the spinning configuration, based on Hughes Aircraft Company designs. The configuration is a dual spin satellite with deployable solar array skirt and a high gain earth oriented antenna. This is in fact the current state of the art for such spacecraft of this configuration. The direct broadcast satellite was selected to be the non-spinning or three-axis stabilized configuration. This design is typical of many communication satellites built by RCA, Ford Aerospace & Communications Corporation and General Electric. It also represents current state of the art technology concerning the subsystems.

A great deal of detailed design information was available on these two spacecraft. This information was utilized in developing the baseline designs, as shown in the following sections. However, only those design aspects which were pertinent to the study have been included here.

5.2 Fixed Services Satellite (FSS)

5.2.1 Baseline Design

The baseline Fixed Services Satellite design selected for this study is based on the Hughes Aircraft Company product line, HS 376. This is a dual-spin satellite with deployable solar array skirt and a high-gain, earth oriented antenna, as illustrated in Figure 5.1.

This spacecraft is designed to provide full functional capability over an 8-year mission life. The mission probability of success, with 16 channels operating, exceeds 0.80. The payload capability is similar to Anik C and SBS, and consists of a shared aperature, dual-polarized antenna system complementing a 16-channel communications repeater. The repeater closely resembles that of Anik C; the antenna reflector and the mechanical deployment features are identical to those of the SBS. Shaped area and regional spot beams are similar to those of GTE's GSTAR (Figure 5.2). The beam shaping technique is identical to that of SBS.

Spacecraft Mass and Power

The mission mass budget, including the derivation of the spacecraft dry mass, is presented in Table 5.1. Table 5.2 gives the spacecraft mass by subsystem. The mass margin for an STS/PAM-D launch is 25.9 kg. This margin is for a satellite with 8 years of stationkeeping propellant. Since most of the subsystem units represent existing hardware, their masses are known with certainty; thus, the 25.9 kg margin is a conservative one.

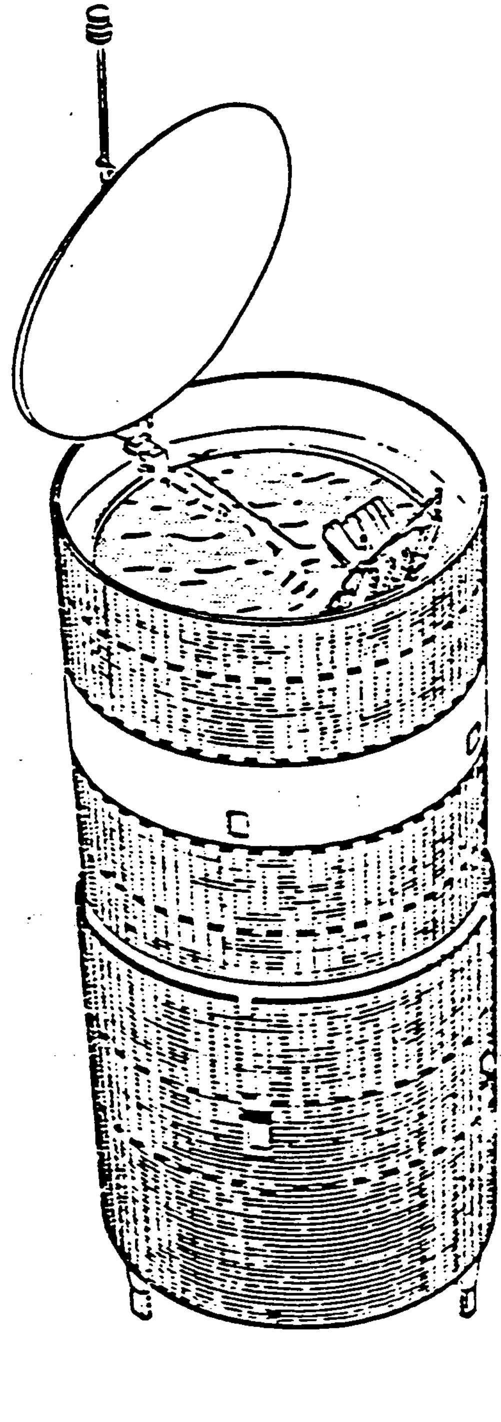

FIGURE 5.1 FSS BASELINE CONFIGURATION

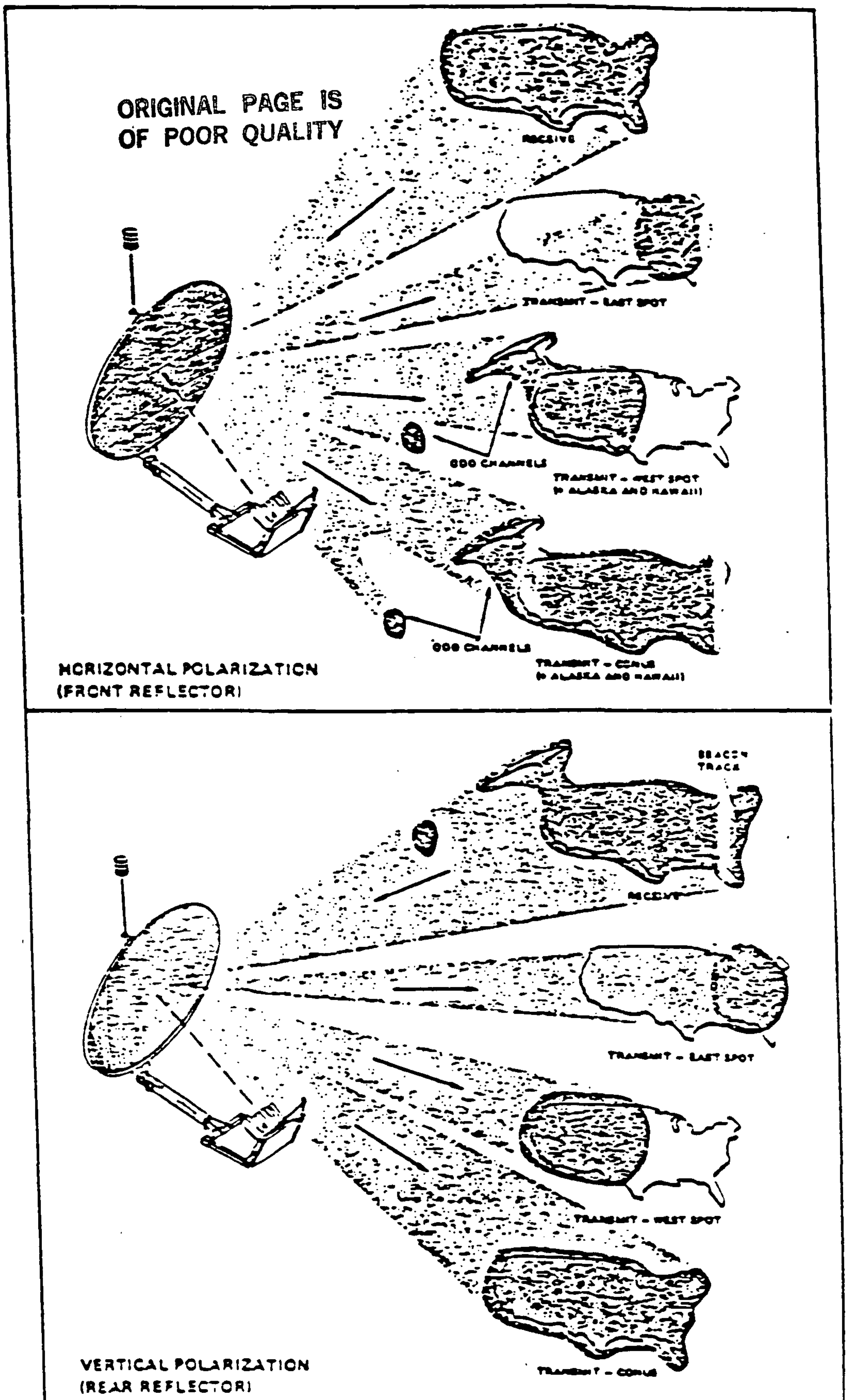

FIGURE 5.2 ANTENNA BEAM AREA AND REGIONAL COVERAGE (FSS)

TABLE 5.1 MISSION SEQUENCED MASS HISTORIES (kilograms)

Mission Sequence	STS/PAM
Mass into transfer orbit	1250.9
(Inclination,deg)	(27)
Hydrazine used in transfer orbit	3.5
Hydrazine used in preburn to augment AKM	75.1
Apogee motor propellant expended	508.1
Hydrazine used in drift orbit	13.8
Spacecraft, beginning of life	650.4
Hydrazine used during 8yr	117.1
Spacecraft allowable dry mass	533.3

TABLE 5.2 MASS SUMMARY (kilograms)

Item	MASS
Subsystem	
Communications	
Antenna	45.0
Repeater	88.9
T,C & R	27.4
Attitude control	25.6
Reaction control	18.2
Electrical power	122.3
Thermal control	20.9
Structure	96.4
Wire harness	27.2
Apogee motor case	31.0
Balance masses	4.8
Spacecraft dry mass	507.7
Total mission propellant load	210.0
Mass margins at 8yr	25.9

TABLE 5.3 POWER SUMMARY

Subsystem	Power Requirement Sunlight	Eclipse
Communications, W	695.0	695.0
Bus, W	121.9	226.3
Total, W	816.9	921.3
Solar array margin, %	3.5	
Battery DOD, %		49.9

The power requirements are summarized in Table 5.3. The solar panels provide a power margin in excess of 3.5 percent after 8 years of operation with 16 channels operating. This provides for uncertainties in the radiation environment. A simple extension of the aft solar panel by 20.3 cm could provide an additional 50 watts. The batteries are sized for 50 percent depth of discharge (DOD) at the beginning of life to ensure 8 years of on-orbit lifetime.

Spacecraft Design

The baseline FSS spacecraft is a spin-stabilized configuration with a deployable antenna system consisting of a dual-gridded shared aperture reflector for communications and a pair of Ku band omni antennas for telemetry and command (T & C). The spacecraft consists of two basic sections: a spinning section which contains the power, propulsion, T & C digital electronics, and most of the attitude control elements, and a despun section containing, essentially, the communications and T & C equipment. Figure 5.3 illustrates the general arrangement,

TABLE 5.4 FSS BASELINE SPACECRAFT SYSTEM CHARACTERISTICS

Attribute	Value	
SIZE, cm.		
Spacecraft diameter	216.4	
Solar drum height		
Forward drum (fixed)	218.2	
Aft drum (extendible)	199.0	
Overall height		
Transfer/drift orbit	281.7	
Geosynchronous orbit	668.8	
Similar designs	SBS, Anik C, Anik D, Palapa B, Westar IV/V, Telstar 3	
MASS, kg.		
Spacecraft/PAM at PAM ignition	3402.4	
Spacecraft in transfer orbit	1251.0	
On station		
BOL	650.5	
EOL, max allowable	533.3	
Spacecraft dry mass	507.4	
Margin	25.9	
STABILIZATION		
Spacecraft/PAM coast	Spacecraft-supplied ANC	
Transfer/drift orbit	Roll-to-pitch inertia ratio greater than 1.1	
Geosynchronous orbit	Gyrostat	
STATIONKEEPING		
	Limit, deg.	Correction Interval, Days
Longitude	±0.05	21
Latitude	±0.05	28
Attitude (nominal)	±0.22	6
MISSION LIFE	8 yr	
RELIABILITY		
Spacecraft at 8 yr, 16 channels operating	0.806	

offering a cutaway view of the spacecraft in its on-orbit operational configuration. The spacecraft system characteristics are summarized in Table 5.4.

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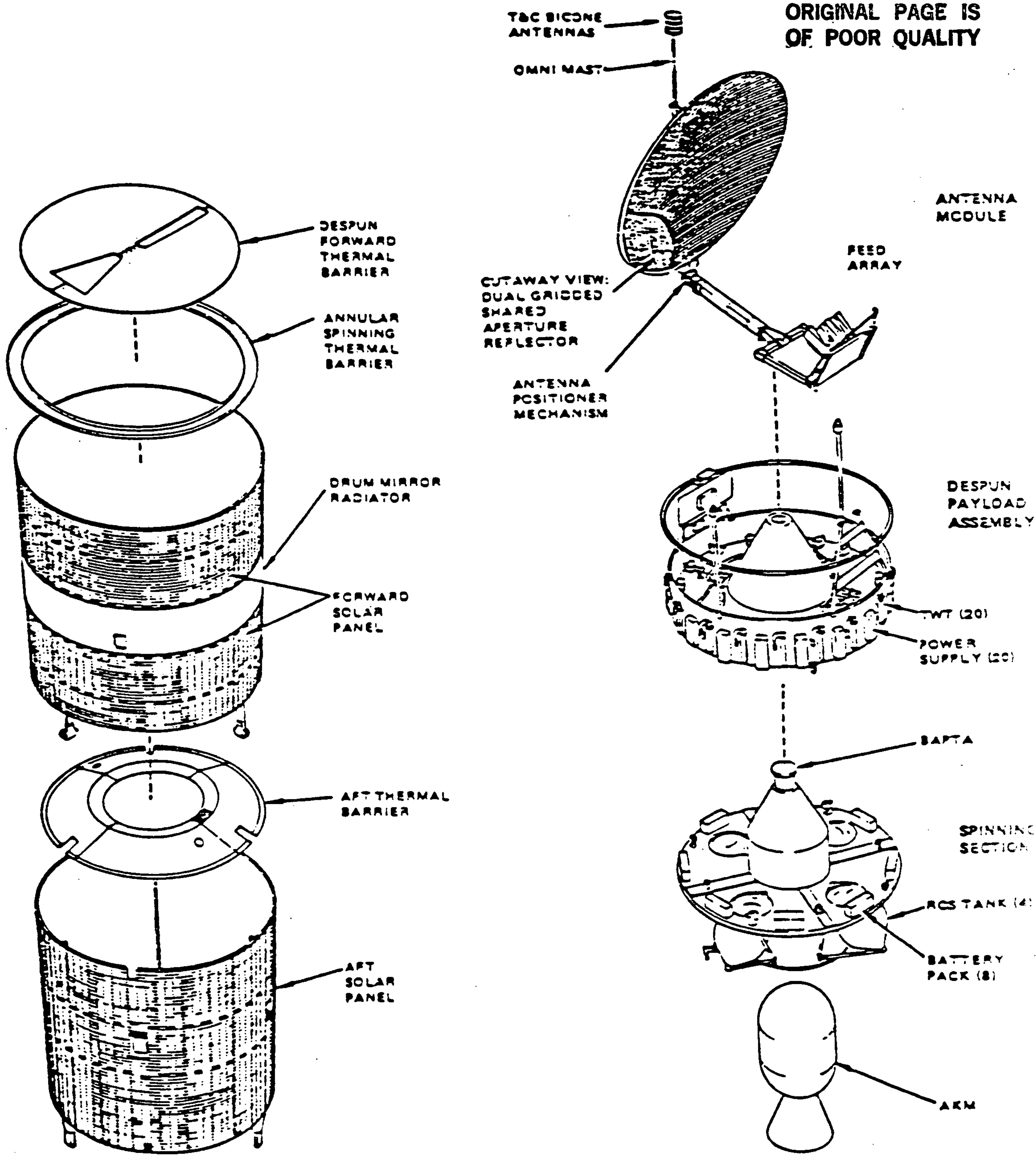


FIGURE 5.3 SPACECRAFT GENERAL ARRANGEMENT OF SUBSYSTEMS (FSS)

TABLE 5.4 PSS BASELINE SPACECRAFT SYSTEM CHARACTERISTICS (cont)

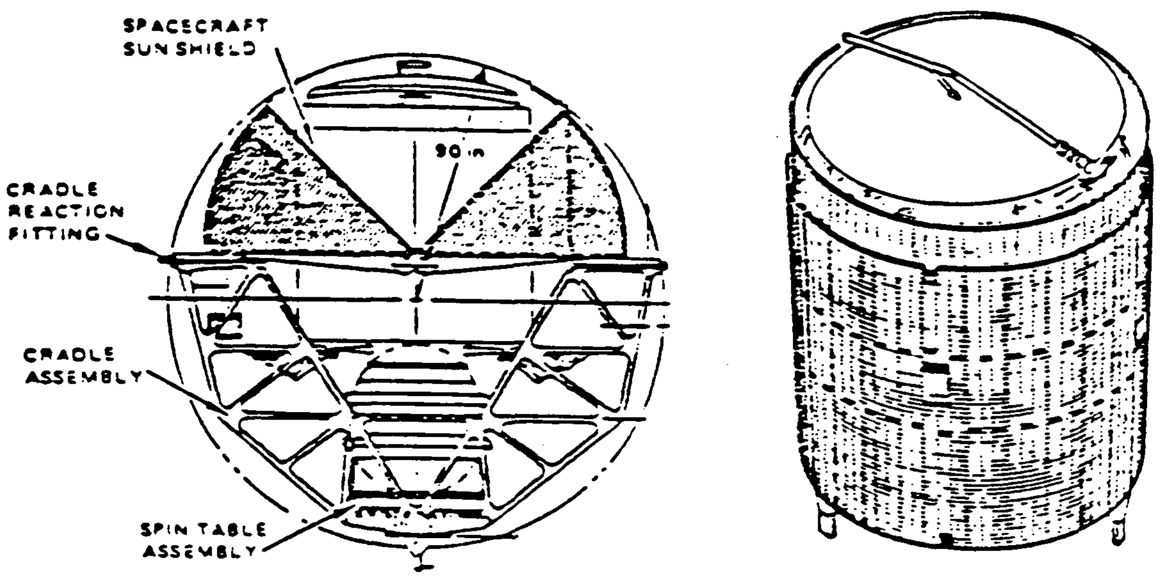
Attribute	Value
COMMUNICATIONS SUBSYSTEM	
Repeater	
Receive frequency band, GHz	14.0 to 14.5
Transmit frequency band, GHz	11.7 to 12.2
No. of channels	16
Channel amplifier redundancy	20 for 16
Channel multiplexing	Even/odd
Usable channel bandwidth, MHz	54
Channel spacing, MHz	61
Receiver redundancy	4 for 2
Receiver noise figure, dB	4.3
Antenna	
Shared aperture diameter, cm	182.7
Focal length, cm	152.3
Polarization	Linear, orthogonal
Coverage	
Receive	CONUS and CONUS + Alaska + Hawaii
Transmit	CONUS, east spot, west spot and CONUS and west spot combined with Alaska + Hawaii
Pointing	RF beacon
Connectivity	Individual channel to beam connectivity command
ATTITUDE CONTROL	
Antenna pointing	Two-axis beacon tracking
Backup mode	Earth sensor
Antenna pointing error (including transients)	
N-S (roll)	± 0.05 degrees
E-W (pitch)	± 0.05 degrees
Beam rotation (yaw)	± 0.25 degrees
PROPULSION	
No. of tanks	4
System construction	Welded titanium
Propellant	Hydrazine
Propellant load, 8 yr mission	210 kg.
Max tank capacity	211 kg.
No. of thrusters	4 (2 radial, 2 axial)
Redundancy	Dual halfsystems

TABLE 5.4 FSS BASELINE SPACECRAFT SYSTEM CHARACTERISTICS (cont)

Attribute	Value
ELECTRICAL POWER	
System	Dual regulated buses with tap limiters
Solar cells	High efficiency K-7; 2 by 6 cm typical
Cover slide thickness	10 mil.
Total array power	
On station (BOL)	
Solstice	1066 W
Equinox	1126 W
On station (EOL at 8 yr)	
Solstice	856 W
Equinox	919 W
Panel margin	3.5%
Battery system	2 Ni-Cd batteries
Measured capacity	27.0 A-hr
Depth of discharge, BOL	Less than 50%
Recharge time at EOL	Less than 19 hr

The spacecraft bus is characterized by its two concentric cylindrical solar panels. The launch configuration (Figure 5.4) provides a compact arrangement, achieved by folding down the omni antenna mast and reflector assembly at their hinge points and retracting the aft solar panel. In the final on-orbit configuration, the spacecraft's spin axis will be parallel to the earth's polar axis and the antenna end will be pointing north.

The two solar panels provide power in excess of 856 watts; at least 31 watts (3.5 percent) of panel power margin exists at the end of life with the payload complement of 16 channels operating simultaneously. The solar panel power prediction is



SUNSHIELD OPEN FOR SPACECRAFT/PAM EJECTION

LAUNCH CONFIGURATION

FIGURE 5.4 SPACECRAFT LAUNCH CONFIGURATION

based on NASA's model for radiation environment, A7 Cycle 20, which is conservative.

Reaction Control Subsystem

The reaction control subsystem (RCS) is typical of the HS 376 spacecraft. This design uses the Palapa B tanks which are large, in order to augment the Star 80 AKM with a preburn to provide a capability to carry heavier payloads.

The key features of the RCS are as follows:

* Gas pressure blowdown design
* Positive propellant settling by centrifugal force
* Two functionally redundant half-subsystems
* Interconnect latch valve for redundancy
* Monopropellant hydrazine propellant
* Conispherical titanium alloy tank design
* All-welded titanium alloy tubing
* Qualified flight hardware

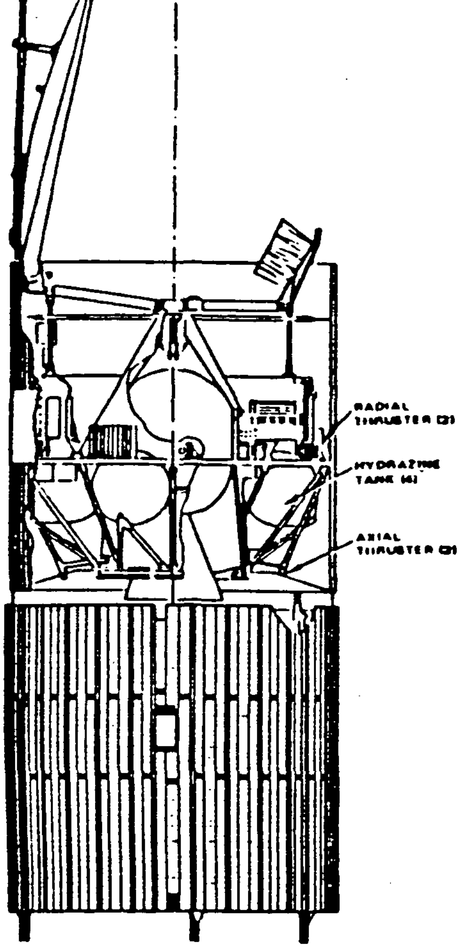
The propellant tank's were selected because their capacity satisfies all requirements of an 8-year mission. The use of redundant half-systems with an interconnect latch valve makes all the propellant available to any thruster. The subsystem design includes redundant heaters, blankets, low emittance tape wrap, and radiation canisters which preclude any operational constraints due to the temperature environment. The gas blowdown feature and centrifugal settling induced by spinning ensure that bubble-free propellant is always available at the tank outlets. The thrusters are capable of performing two times the required operating sequence with thrust predictability maintained to within +4 percent of nominal throughout the operational lifetime. There are no restrictions on the number of pulses or the length of continuous burn.

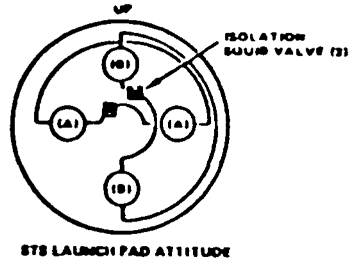
TABLE 5.5 RCS PROPELLANT ALLOCATION SUMMARY

Manuever	Thruster	Magnitude	Hydrazine Mass kg	(lbs)
Active nutation control (before PAM ignition)	Radial		0.2	(0.5)
Transfer orbit reorientation	Axial	134 deg	3.5	(7.7)
Preburn before AKM fire	Axial	141.7 m/sec (465 fps)	75.1	(165.6)
Injection errors (acquisition)	Axial (N-S) Radial (E-W)	36.6 m/sec (120 fps)	11.1	(24.4)
Spacecraft spin axis alignment	Axial	114 deg	2.8	(6.1)
N-S stationkeeping	Axial	3996.6m/sec (1311.0 fps)	110.3	(243.2)
E-W stationkeeping	Radial	0.8m/sec (2.7 fps)	0.4	(0.8)
Attitude control	Axial	184 deg	5.5	12.2
Repositioning	Radial	2.9m/sec 9.5 fps	0.9	(2.0)
Total hydrazine required			209.8	(462.5)
Maximum tank capacity			210.9	(465.0)

Table 5.5 illustrates the propellant budget for the FSS baseline design. Note that the two budget propellant users are N-S stationkeeping and the preburn to assist the AKM.

In summary, the RCS, shown in Figure 5.5, is located on the spinning section of the spacecraft, and operates in a pressure blowdown mode. Positive delivery of monopropellant hydrazine from the conispherical tanks is ensured by the influence of the local gravity associated with the spinning environment. When commanded, the propellant valve opens and hydrazine is pressure-fed to the thrusters which catalytically decompose it to produce the required thrust.





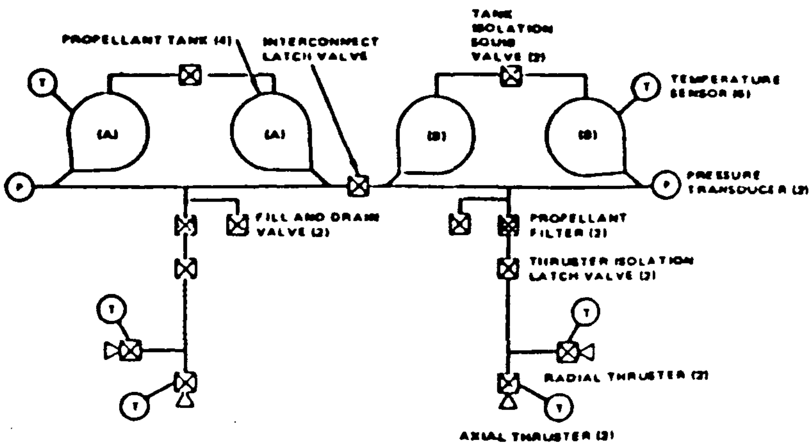


FIGURE 5.5 RCS SCHEMATIC (PSS)

This subsystem consists of two half subsystems, providing full hardware redundancy, separated by interconnect latch valve, each containing half the propellant load required for the mission. Each half subsystem consists of two catalytic hydrazine thrusters with a common isolation latch valve, one propellant filter, two propellant tanks, one tank isolation squib valve, one pressure transducer, one fill and drain valve, and three temperature sensors. If a thruster valve fails, the two tanks of this subsystem can be connected into the other half subsystem by commanding the interconnect latch valve to open and the thruster isolation latch valve to close.

Each RCS half subsystem contains a squib valve in the gas manifold connecting the two tanks. The opening of these valves is delayed until the final spacecraft erection to prevent

propellant or gas migration and inbalance resulting from the spacecraft's orientation during launch and transfer orbit.

Electrical Power Subsystem

The Power subsystem for the FSS baseline design is essentially identical to that used on SBS and Palapa B. This design provides the following:

* Power for ten 16-watt and six 14-watt K<u> band communications TWTAs over an 8-year mission life
* Solar panel margin at end of life (EOL) to compensate for thermal and radiation environment uncertainties
* Dual, independent, balanced load electrical buses for redundancy
* Use of the medium charge array to augment main panel power at summer solstice
* Two flight-qualified nickel-cadmium batteries
* Battery depth of discharge not exceeding 50 percent at BOL
* Multiple battery charge rates
* Individual battery cell voltage telemetry for efficient battery management
* Bus voltage control during eclipse and sunlight

Subsystem Description

The main components of the power subsystem are the solar arrays, batteries, bus voltage limiters, discharge controller, charge/reconditioning unit, battery cell voltage monitors, solar drum positioners, and switching units for heaters and the telemetry/ranging mode. Table 5.6 lists the physical characteristics of this subsystem. The major components are located on the spinning section of the spacecraft, as shown in Figure 5.6. Power is delivered to the despun section via the bearing and power transfer assembly (BAPTA).

Solar arrays consist of two concentric cylindrical panels of n-p silicon solar cells. The forward panel is attached to the main structure and is divided into two arrays separated by a

TABLE 5.6 PHYSICAL CHARACTERISTICS

Unit	Quantity per Spacecraft	Total Weight kg (lb)	Design Features
Solar Array			K-7 solar cells, 10 mil fused silic[illegible] cover glasses
Forward panel electrical assembly	1	18.1 (40.0)	
Forward panel substrate	1	-	
Aft panel electrical assembly	1	21.3 (47.0)	
Aft panel substrates	1	-	
Racks	3	2.1 (4.7)	
Solar drum positioner mechanism	3	4.7 (10.3)	Redundant motors
Solar panel attachment	8	-	
Batteries	2	63.3 (139.5)	27 A-hr cells
Discharge controller	1	6.4 (14.1)	One redundant PWM regulator per batte[illegible]
Bus limiter	2	2.8 (6.1)	Four circuits per u[illegible] functionally redunda[illegible]
Charge/reconditioning unit	1	0.9 (1.9)	Redundant relays, ground commanded
Battery cell voltage monitor	2	0.7 (1.6)	Hybrid microcircuits
Battery heater controller	2	0.5 (1.2)	
Pyrotechnic switch unit	1	0.3 (0.6)	
Current sensors	8	0.4 (1.0)	Redundant sense resistors
Medium array switch unit	1	0.7 (1.6)	Redundant relays, ground commanded

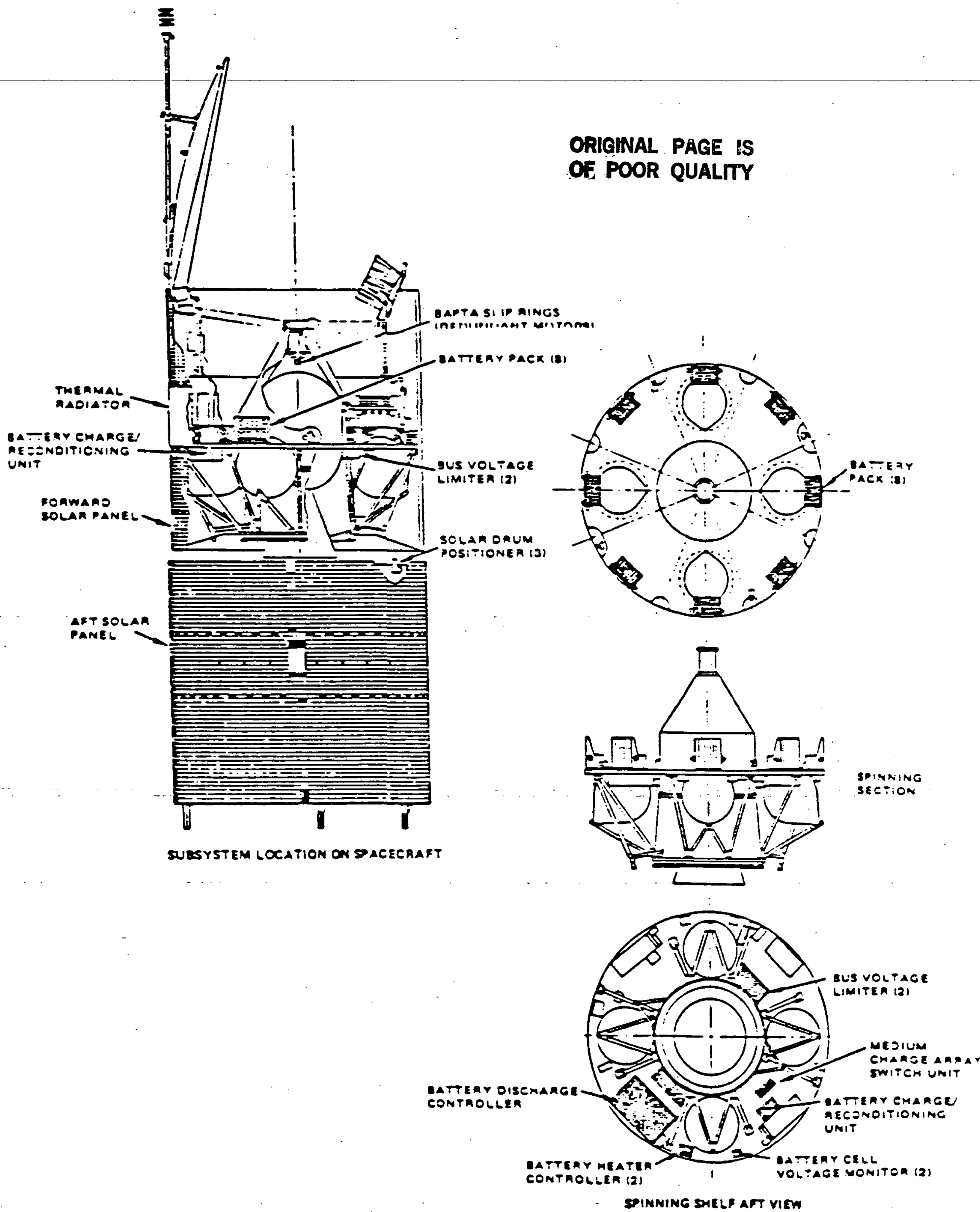


FIGURE 5.6 ELECTRICAL POWER SUBSYSTEM ELEMENTS (FSS)

thermal radiator band, while the aft panel is retracted over the forward panel during transfer orbit and extended to its operating position in geosynchronous orbit. This aft panel is supported by three longitudinal rack and pinion drives and is extended from the main structure by the solar drum positioners. Redundant flexible ribbon cables are used for electrical connections with the aft panel. In transfer orbit, solar power is provided by the aft panel only.

Eight nickel-cadmium battery packs, each with eight cells, are located on the periphery of the spinning shelf in proximity to the thermal radiator. The packs are connected in two 32-cell, 27 A-hr batteries. The main power dissipating components, bus voltage limiters, and battery discharge controller are also mounted on the spinning shelf.

Operational Characteristics

Spacecraft power is provided by two independent and balanced load electrical buses, as shown in the block diagram of Figure 5.7. The main solar arrays are connected to the buses through redundant isolation diodes. Redundant bus voltage limiters act to limit the bus voltage to 30.0 ± 0.5 volts, except for a brief rise to 42.5 volts on exit from eclipse. The limiters operate as partial or tap shunt regulators, so as to load a portion of each array rather than the main bus. This permits control of the voltage while limiting the maximum thermal dissipation. In steady operation, the solar arrays supply all the required power during sunlight conditions.

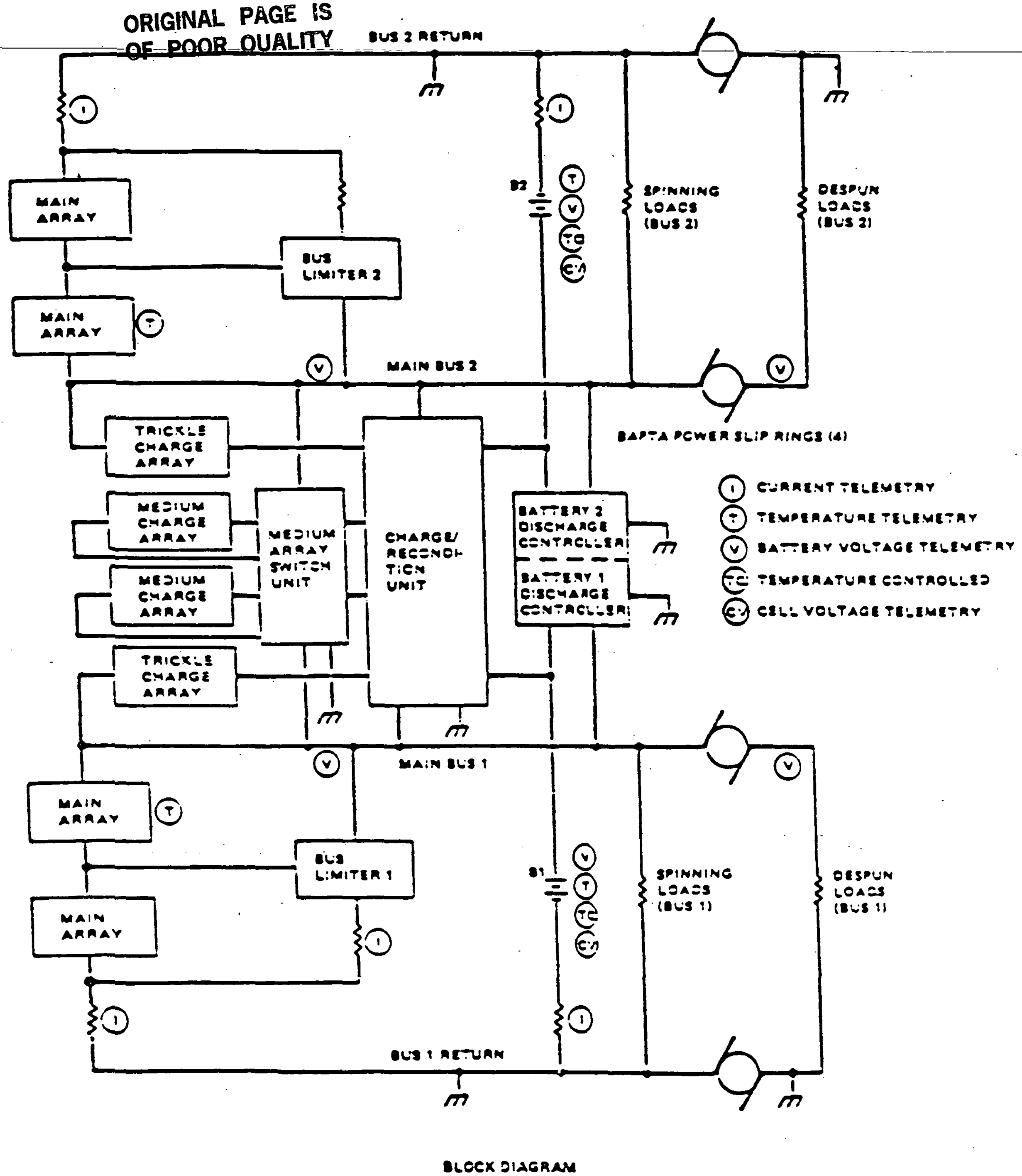


FIGURE 5.7 ELECTRIC POWER SUBSYSTEM BLOCK DIAGRAM (FSS)

During eclipse, bus power is delivered by the two batteries which automatically assume the load as the solar array output diminishes with the onset of the eclipse. Batteries are connected to the spacecraft power buses through the discharge controller which regulates each bus at 29.1±0.1 volts. During sunlight operation, the discharge controller is in standby mode since the main bus voltage is greater than the controller setpoint. In the event that additional power is required to supplement the solar array for power transients or fault clearing, the battery will automatically come on line to supply additional power.

Battery charge current is supplied by the current limited, boost charge arrays which are connected in series with the main arrays. Two trickle charge arrays and two medium rate charge arrays permit a selection of multiple charge rates throughout the mission. Between successive eclipses, batteries are normally charged in sequence at high rate, using all four charge arrays at a time. During noneclipse seasons, the batteries are trickle charged. All battery charging opertions are controlled by ground commands which switch relays in the battery charge/reconditioning unit and medium array switch unit.

A summary of design and performance characteristics is presented in Table 5.7. These data include voltages, power capacities, and charging currents.

5.2.2 Ion Propulsion Impact

The baseline Fixed Services Satellite presented above has been modified to include the use of ion propulsion for NSSK using

TABLE 5.7 DESIGN AND PERFORMANCE CHARACTERISTICS

	BOL		EOL (8 YR)
Bus Voltage*			
Sunlight operation		30.0 + 0.5 V	
Eclipse operation		29.1 + 0.10 V	
Posteclipse transient		42.5 V max	
Main Solar Array			
Power capability			
Summer solstice	1052 W		856 W
Autumn equinox	1129 W		919 W
Power margin at summer solstice	209 W		39 W
Power margin at autumn equinox	197 W		31 W
Battery Charge array			
Available charge current			
Trickle, Summer Solstice	0.43 A		0.36 A
High rate, Autumn Equinox	2.45 A		2.05 A
Maximum recharge time for 2 batteries	14.5 hrs		19.1 hrs
Batteries			
Number		2	
Cells per battery		32	
A-hr rating, each battery		27	
Maximum depth of discharge			
BOL		50%	
Temperature control range		5° to 20° C (41° to 68° F)	
Battery Discharge Controller			
Rated steady state output current (per bus)		23.6 A	
Current limit (per bus)		31 A	
TWTA Shutoff Voltage			
Bus voltage		<26.5 V	
Solar Array Deployment			
Extension distance		210 cm (82.7 in)	
Deployment time (at 25 steps/sec)		75 min.	

* With distribution losses, voltage at the load is 28V minimum

NASA developed technology. The baseline satellite has thus been reconfigured with the new improved technology - ion propulsion - and the DOMSAT Model has been run with the resulting changed spacecraft parameters. Foreign technology is also reviewed — differences are discussed in following paragraphs. The ion propulsion system selected for NSSK of this size spacecraft uses gas such as xenon. Its duty cycle of usage is assumed to be three hours a day on the average. A single thruster is assumed to be used with a backup thruster on the spacecraft. The NSSK requirement represents an average velocity increment of 45.8 m/s/yr. This represents an average acceleration of 1.45×10^{-6} m/s^2 . Both spacecraft are assumed to have a BOL mass in orbit of 625 kg. This leads to a daily impulse requirement of 78.4 N-S.

In order to use the thruster effectively two effects must be accounted for. The thruster will be canted away from the solar arrays; in the case of a non-spinning satellite, up to an angle of 30 degrees. In the case of a spinner, such as the Fixed Services Satellite, there are other losses associated with impingement of the plume on the structure. Thus, this factor has been accounted for by assuming a loss of effectiveness of 13.4% due to either canting or plume impingement. In addition to this, the three-hour thrust interval requires that some non-ideal impulse be applied as the spacecraft moves around the orbit. Thus, the thrust effectiveness, due to a finite burn time of three hours is calculated to be 97.45%. Combining these two factors leads to an overall thrust effectiveness of 84.39%. Therefore, the total equivalent daily impulse required of the

thruster is 92.9% N-S. This leads to a thrust level over a 3-hour period per day of 8.6 mN. Using an 8-year life for this FSS mission, several factors have been developed that are associated with the design of the subsystem.

The important design parameters that were derived based on the above assumptions are as follows. The beam current is 0.18 amperes with a specific impulse of 2,926 seconds. This leads to an acceleration voltage of 923.9 volts and a power requirement of 276.6 watts. The propellant load for 8 years is calculated to be 9.39 kg. The power processor mass is calculated to be 5.54 kg and the thruster mass is 4.56 kg per thruster. In addition to this, a tank is needed to hold the xenon. Assuming a 5% margin of xenon mass which gives a total propellant mass of 9.86 kg, the volume of the required tank at 75°F in a 4200 PSIG is 593.9 cubic centimeters. This results in a spherical tank of radius 9.7 centimeters and a mass of roughly 3 kg.

The amount of hydrazine allotted for NSSK in the baseline FSS propellant budget is 110 kg. Thus, there is a significant potential savings in terms of overall spacecraft mass, which could be used in other areas. The total differential savings between the elimination of the hydrazine and the addition of the xenon is approximately 101 kg. In addition to this there is the added savings of smaller propellant tanks for hydrazine. The mass of the dry ion-thruster system which is approximately 20 kg with plumbing and harnesses must also be added in. Net savings for the use of ion propulsion is therefore approximately 90 kg for the 8-year mission. This assumes that the baseline battery

C-2

propulsion with a duty cycle that would be sufficient to maintain orbital control. If this is not the case, additional batteries and solar cells may have to be added or committed to the ion thruster system.

Foreign competition in ion propulsion for NSSK is discussed in Section 4.3.1 and is represented largely by the Germans with the Japanese following closely. The Germans are developing the RIT-10 and have had some flight experience with it. This is a thruster which uses mercury as a propellant and produces a thrust of approximately 10 mN. It has a beam current of approximately 0.22 amps at 1,500 volts. It requires 375 watts of power and has a tested lifetime of 8,150 hours. This thruster has also been used with xenon with which it requires slightly more electrical power. Thrust with xenon ranges from 7 to 14 mN, and could therefore perform NSSK for the FSS. It has an associated specific impulse of 2,540 sec. This implies that it is not as quite a high performer as the NASA inert gas system being developed by Hughes Aircraft.

The Japanese have also been advancing quickly in this area. They have developed a 5 cm mercury ion-thruster which was flown on ETS-III. The thrust level was only 2 mN at specific impulse of 2,357 seconds. The Japanese are currently developing a 20 mN type thruster using xenon. This is planned for a 1992 flight. Thus, for the time frame of interest, it is felt that the Japanese will not have a competitive system.

5.2.3 Solar Cell Impact

The effect of new solar cell technology on FSS was

evaluated by increasing the cell efficiency from 13% to 18% and making the appropriate adjustments in solar array size, structural mass, thermal requirements, etc. The results indicate some improvement in payload utilization and reduced spacecraft mass, (14 kilograms) as indicated in Table 5.8.

5.2.4 Point Design with Improvements

Two point designs of FSS satellites were developed, one which includes improved solar cells and the other an ion propulsion NSSK system. Both designs resulted in a mass savings at liftoff which was then "put back" into each satellite to extend its capability. The satellite with the ion thruster design had sufficient mass savings to allow for four (4) added transponders and enough additional propulsion to extend the lifetime two (2) years. This extended capability satellite has the same mass as the baseline satellite (the satellite without technology improvements). The satellite designed with Gallium Arsenide solar cells may be designed with two (2) additional transponders, without increasing the liftoff mass beyond the baseline mass.

Table 5.8 summarizes the mass breakdown of the baseline satellite and of the two improved satellites, both with the mass savings and with the extended capability.

5.3 Direct Broadcast Satellite (DBS)

5.3.1 Baseline Design

The baseline Direct Broadcast Satellite design selected for this study is based on the General Electric communications

satellite product line. This is typified by BSE, BS-2, and DSCS III. The selected DBS is three-axis stabilized and has a launch mass of 1247 kg. Its configuration is illustrated in Figure 5.8. Communications Corporation, thus, making it representative of most three-axis stabilized DBS's in its mass class.

This design is similar to that of RCA and Ford Aerospace and

TABLE 5.8 MASS SUMMARY OF IMPROVED FSS SATELLITE (kg)

		With GaAs		With Ion NSSK	
Subsystem	Baseline	Reduced Mass	Extended Capability*	Reduced Mass	Extended Capability+
Communications					
Antenna	45.0	45.0	45.0	45.0	45.0
Repeater	88.9	88.9	96.6	88.9	102.4
T C & R	27.4	27.4	27.4	27.4	27.4
ACS	25.6	25.6	25.6	25.6	25.6
RCS (Hydrazine)	18.2	18.2	18.2	13.2	13.3
Ion NSSK				18.3	18.3
EPS	122.3	111.3	121.5	122.3	144.5
TCS	20.9	20.9	21.3	20.9	21.8
Structure	96.4	93.3	94.2	96.4	102.0
Harness	27.2	27.2	27.2	27.2	27.7
AKM Case	31.0	31.0	31.0	31.0	31.0
Balance Mass	4.8	4.8	4.8	4.8	4.8
EOM Mass	507.7	493.6	512.8	521.0	563.8
Mission N2H4	209.7	209.7	209.7	99.5	140.8
He Pressurant	.1	.1	.1	.1	.1
Xenon Load	0.0	0.0	0.0	9.4	11.7
Satellite Liftoff Mass**	717.5	703.4	722.6	630.0	716.4
Design Margin	25.5	25.5	20.1	25.5	26.3
Satellite Liftoff Mass Plus Design Margin	743.0	728.9	742.7	655.5	742.7

* With 2 additional repeaters
\+ With 4 additional repeaters and 2 extra years
** Excludes PAMD mass, cradle and apogee kickmotor propellant

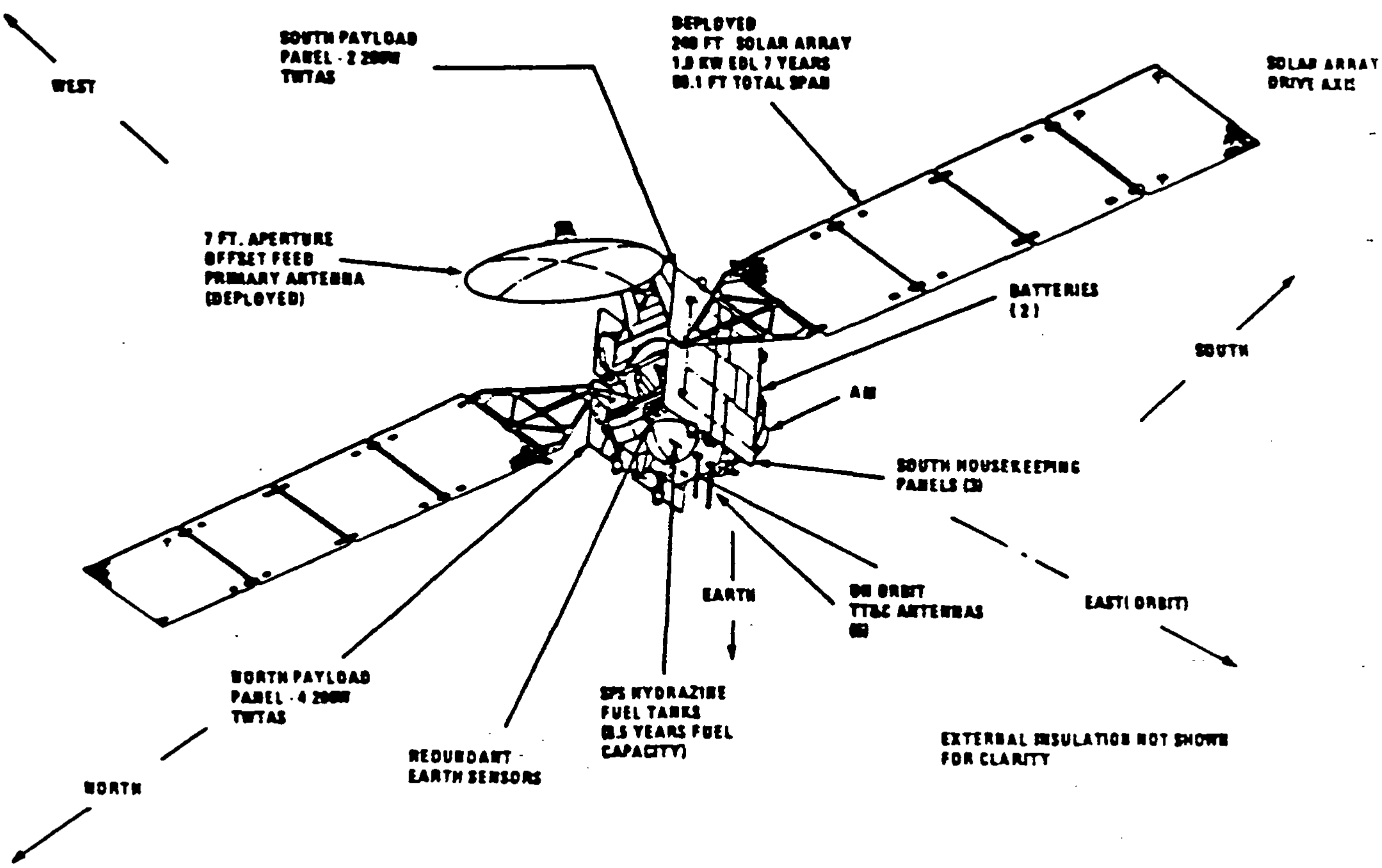


FIGURE 5.8 BASELINE DBS ORBITAL CONFIGURATION

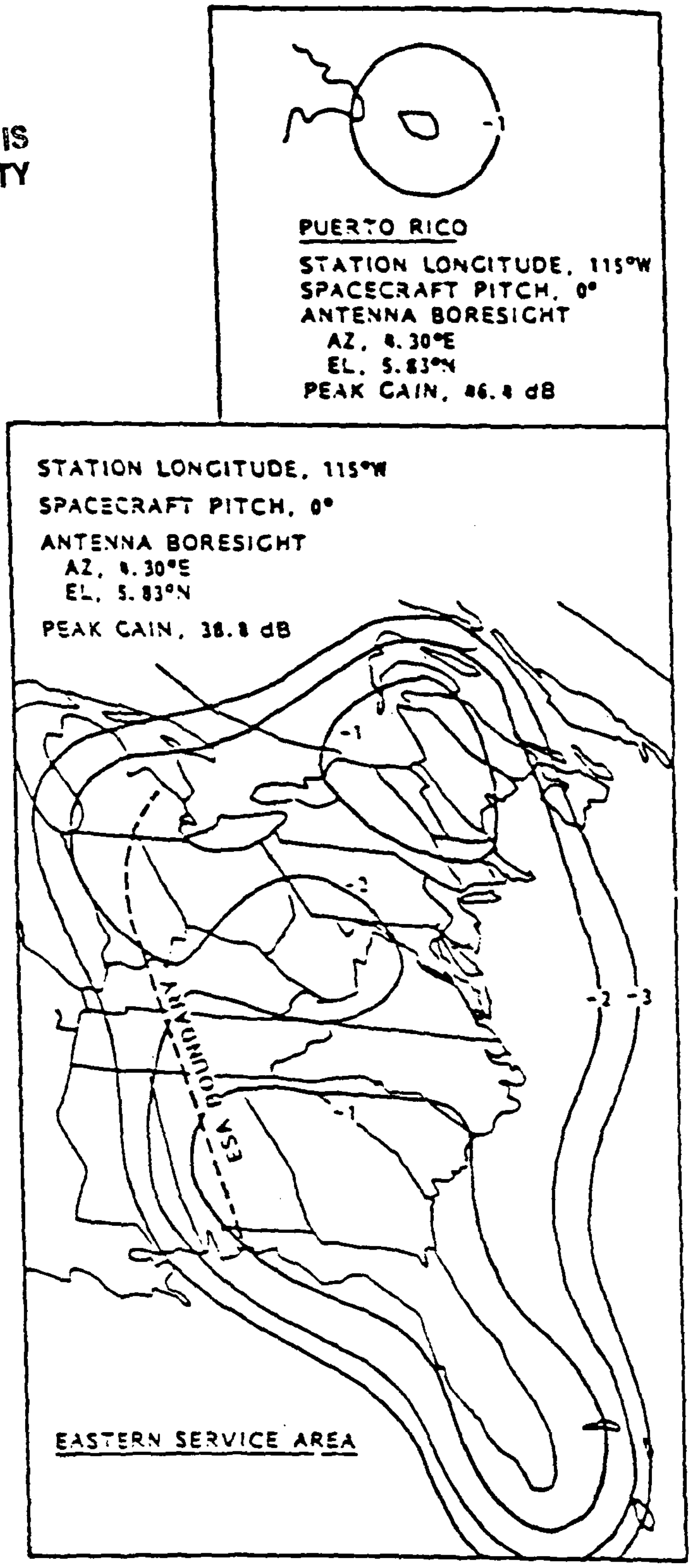


FIGURE 5.9 ANTENNA COVERAGE OF EASTERN SERVICE AREA (DBS)

ELECTRICAL POWER

SOLAR ARRAY	OUTPUT (WATTS)	MARGIN (WATTS)	MARGIN (%)
• TRANSFER ORBIT	196	22	11
• SUMMER SOLSTICE			
7 YEARS	1968	132	6.7
10 YEARS	1909	73	3.8
• EQUINOX			
7 YEARS	2230	325.8	14.6
10 YEARS	2134	260.6	12.2

BATTERY CAPACITY

- ECLIPSE - NORMAL • 43.5% DOD, SPECIFIED VALUE - 45%
- EMERGENCY • 58.7% DOD, SPECIFIED VALUE - 60%

ATTITUDE DETERMINATION AND CONTROL

ACTIVE NUTATION CONTROL

- CONE ANGLE THRESHOLD (MIN) — • 0.25 DEGREES
- CONTROL RANGE — • > 100 X ENERGY DISSIPATION FROM ALL SOURCES: 0.088°/SEC NUTATION REMOVAL RATE.

SPIN PHASE

- ATTITUDE DETERM. ACCURACY — • 0.30° 3σ
- PRECESSION RESOLUTION — • 0.02° PER 1.5°/MIN
- NUTATION DAMPING RATE — • 0.088°/SEC NUTATION REMOVAL RATE
- SPIN RATE — • 46 RPM ± 5 RPM

DESPIN PHASE

- DESPIN TIME — • 4 - 8 MIN
- FINAL RATES — • 1 RPM ABOUT SPIN AXIS (BEFORE SOLAR ARRAY DEPLOYMENT)

SUN ACQUISITION

- INITIAL CONDITIONS — • < 1°/SEC PER AXIS (ANY ATTITUDE)
- ACCURACY — • ±5° WRT SUNLINE
- ACQUISITION TIME — • 40 MINUTES AFTER SOLAR ARRAY DEPLOYMENT

EARTH ACQUISITION

- INITIAL CONDITIONS — • < 1°/SEC PER AXIS
- ACCURACY — • ±2° PITCH, ROLL: ±5° YAW
- ACQUISITION TIME — • < 1 HOUR AFTER SUN ACQUISITION

WHEEL CAPTURE

- TIME TO ACHIEVE NORMAL MODE — • < 30 MINUTES AFTER EARTH ACQUISITION
- POINTING ACCURACY — • 0.138° P: 0.147° R: 0.78° Y - 3σ
- STABILITY MARGIN — • > 3X WRT CONTROL LOOP GAINS
- MOMENTUM CAPACITY — • 1.3 FT-LB-SEC EACH OF 4 WHEELS

OFFSET POINTING

- RANGE — • ±6° PITCH: ±2° ROLL
- RESOLUTION — • 0.01°

STATIONKEEPING

- POINTING ACCURACY — • 0.27° 3σ P; R: 0.75° 3σ Y
- STABILITY MARGIN — • > 3 X WRT CONTROL LOOP GAINS

SOLAR ARRAY CONTROL

- ACCURACY — • ±1.0 DEGREE

REACTION CONTROL

PROPELLANT TANKS

- SIZE — • 2 - 22.75" I.D. SPHERICAL TANKS
- CAPACITY — • +20% FUEL MARGIN OVER NOMINAL ON-STATION HYDRAZINE PROPELLANT BUDGET

THRUSTER AND PROPELLANT VALVE ASS'Y

- THRUST LEVEL — • 1.0 LBF INITIALLY
- TOTAL IMPULSE — • ANY TPVA • 200,000 N-SEC.
- DUTY CYCLE — • EACH TPVA CAPABLE OF MIN. IMPULSE BURN OF 0.035 N-SEC FOR 1.5 HOURS. EACH TPVA IS CAPABLE OF 90,000 ON-OFF CYCLES.

THERMAL CONTROL

HEAT REJECTION CAPABILITY — • NORTH AND SOUTH TRANSPONDER EQUIPMENT PANELS ARE SIZED TO REJECT 10% MORE DISSIPATED ENERGY THAN THAT PREDICTED FOR THE TWTA'S

HEATER CAPACITY — • SOLAR ARRAY AND HEATERS ARE SIZED TO PROVIDE > 20% MORE HEAT ENERGY THAN THAT PREDICTED

STRUCTURE

DESIGN LAUNCH WEIGHT — • +10% MARGIN USED TO DESIGN PRIMARY STRUCTURE

STRENGTH

- BUCKLING — • 10% MARGIN OF SAFETY
- YIELD — • 1.5 X FLIGHT LOADS

VIBRATION

- STRUCTURE
- SOLAR ARRAY — • > 0.45 Hz FIRST MODE FOR 58 FT SPAN

THERMAL DISTORTION

- ANTENNA REFLECTOR — • MAXIMUM THERMAL DISTORTION
  - ±0.003" DECENTER
  - ±0.011" DEFOCUS

APOGEE MOTOR

STS/PAM-D LAUNCH

- STAR 30 D — • ΔV = 1745 m/SEC NOM. TO 2746 LB SPACECRAFT MASS AT TIME OF FIRING
  - • OFF-LOAD CAPACITY OF ~52 LBS.

ARIANE LAUNCH

- STAR 30B — • ΔV = 1497 m/SEC TO 2508 LB SPACECRAFT MASS AT FIRING
  - • OFF-LOAD CAPACITY OF ~102 LBS

MECHANISMS

SOLAR ARRAY DEPLOYMENT — • EXCEEDS REQUIRED LATCHING FORCE BY MORE THAN 3:1

SOLAR ARRAY DRIVE — • OVER 3:1 TORQUE MARGIN ON DRIVE MOTOR, 20 FT-LBS EACH MOTOR

ANTENNA DEPLOYMENT — • OVER 3:1 TORQUE MARGIN ON POWER HINGE

SERVICE LIFE

DESIGN/EXPENDABLES — • MINIMUM IN-ORBIT SERVICE LIFE IS SEVEN YEARS. HYDRAZINE FUEL CAPACITY SIZED FOR 8.5 YEARS

GRADUAL DEGRADATION — • MEAN DESIGN LIFE OF TEN YEARS ON OSR ABSORPTIVITY AND SOLAR CELL DEGRADATION

RELIABILITY — • PROBABILITY OF SURVIVAL AFTER SEVEN YEARS IN ORBIT IS IN EXCESS OF 0.836

Mass

STS/PAM-D LAUNCH — • 82 LB MARGIN, ~7.5% OF DRY

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FIGURE 5.10 DBS SPACECRAFT PERFORMANCE SUMMARY

Except for orbit eclipse periods, this Direct Broadcast Spacecraft will provide three continuously operating television channels in the 17/12 GHz frequency with an RF output of 200 watts per channel. The spacecraft is provisioned for seven years operational service life and designed with sufficient redundancy for ten years. Its coverage area (Eastern Service Area) is illustrated in Figure 5.9.

A complete accounting of the baseline bus performance is presented in Figure 5.10. Included are power and mass margins, attitude determination accuracies, and propellant capacity.

Reliability

Spacecraft predicted reliability is better than 0.8 after seven years. Table 5.9 shows the predicted reliability on a subsystem basis, after seven years.

The predicted value of 0.844 is based on the probability of 0.933 of acquiring the required orbital station. If unity is assumed, the predicted value at seven years is 0.885. Table 5.10 shows the predicted probability of survival for seven and ten

TABLE 5.9 SEVEN-YEAR RELIABILITY ESTIMATE

Subsystem	Predicted Value
Communications	0.960495
Telemetry, Tracking, and Command	0.966081
Electrical Power	0.969717
Attitude Determination and Control	0.953745
Reaction Control	0.995976
Thermal Control	0.999968
Mechanical/Structure	0.994206
Apogee Motor	0.993410

years for both on-station acquisition assumptions of 1.0 and 0.993. It also shows the expected survival time for a probability of success of 0.8 for both conditions.

Figure 5.11 is a spacecraft system reliability summary showing each subsystem, its components, and associated probabilities of survival. Probabilities are for 7 years on-orbit unless noted as transfer orbit functions.

Communications

The communications design provides a balance between a reliable hard-ware configuration and a high performance television transmission system. The Communications Subsystem is compatible with either a Thomson or a Telefunken TWT. All transponder components are located on North and South panels as shown in Figure 5.12. These panels are removable as self contained modules. Most of the communications components are mounted on the North panel, with the South panel housing the two complete transmitter chains for Channel A. The input and output switching is also included on the South panel so that only a single input and output waveguide running to the multiplexers on the North panel is necessary. The symmetry of the TWTA

TABLE 5.10 PROBABILITY OF SPACECRAFT SURVIVAL

Probability of On-station Acquisition	7-Year Predicted Probability of Survival	Survival Time at 0.8	10-Year Predicted Probability of Survival
1,000	0.885	9.7 years	0.791
0.993	0.844	8.3 years	0.739

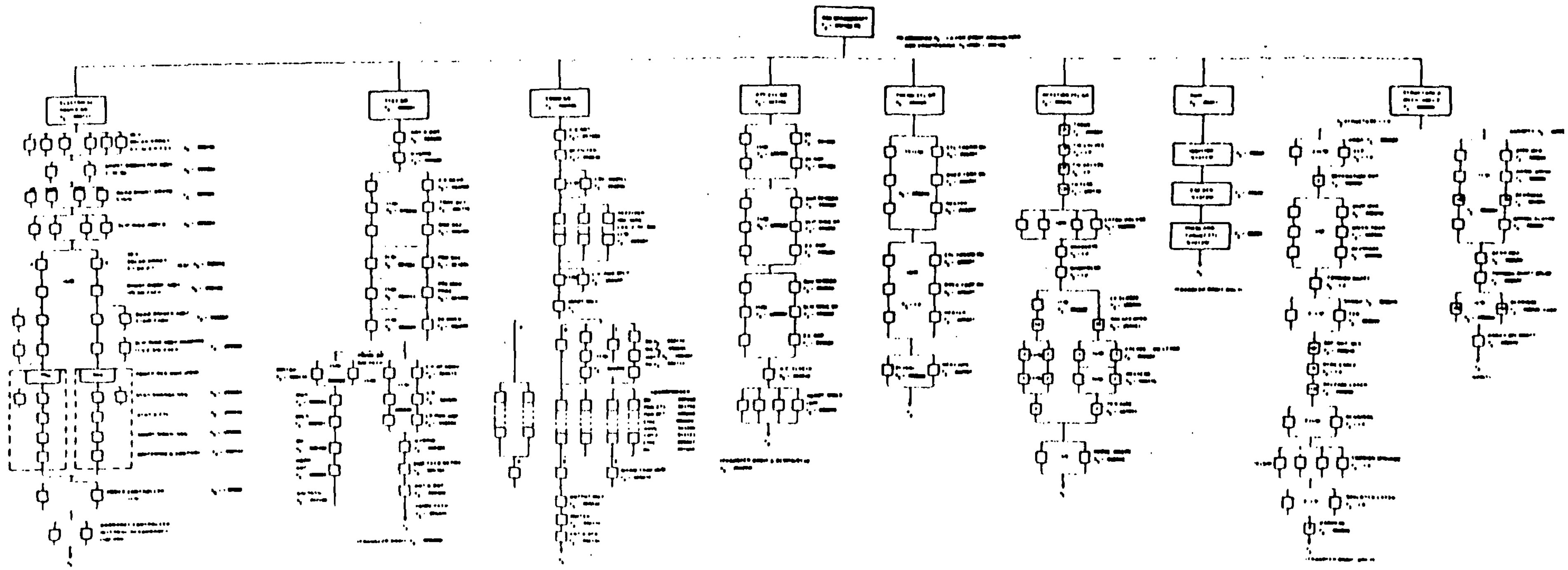

FIGURE 5.11 BASELINE RELIABILITY SUMMARY (DBS)

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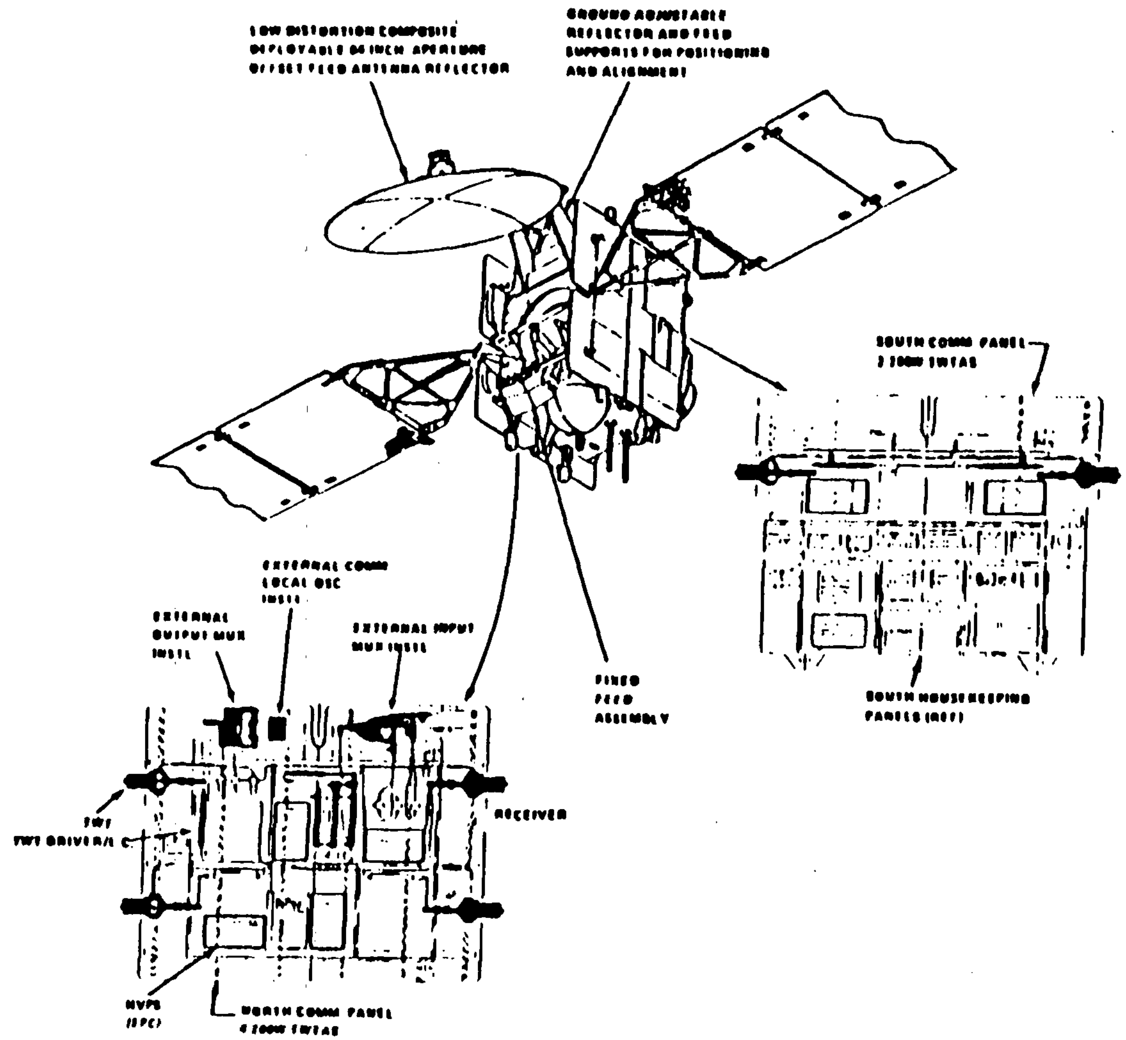


FIGURE 5.12 COMMUNICATIONS MAJOR ASSEMBLIES (DBS)

arrangement facilitates thermal dissipation. All TWTA collectors extend beyond the edge of the panel and radiate directly to space. Each of the two panels is served by a dedicated Power Controller. This provides maximum control flexibility and minimum harness connections between panels. The simplified communications block diagram is shown in Figure 5.13. The transmitter switching matrix of Figure 5.14 indicates the required position of the waveguide switches for the various TWTA/Channel arrangement.

Spacecraft Design

Figures 5.15 and 5.16 summarize the many design features of each subsystem, list mass and power budgets, and illustrate the spacecraft block diagram. The spacecraft is fully compatible with STS/PAM-D launch vehicle interfaces and constraints. When fully deployed, the overall length of the spacecraft from the tip of one solar array to the other is 17.5 meters. In the stowed configuration the overall height from the separation plane to the top of the TT&C antenna is 2 1/2 meters. When deployed in the orbital configuration, the height is 4 meters. To maintain transponder temperatures, 15.8 square meters of north and south radiating areas are provided. Three removable south panels support all spacecraft bus (housekeeping) high heat generating components. The two battery assemblies on the south panel are thermally isolated and individually temperature controlled.

The transponder equipment installation has been organized by grouping the six 200 watt TWTAs and electronics on two removable modular north and south panels. The north panel supports four

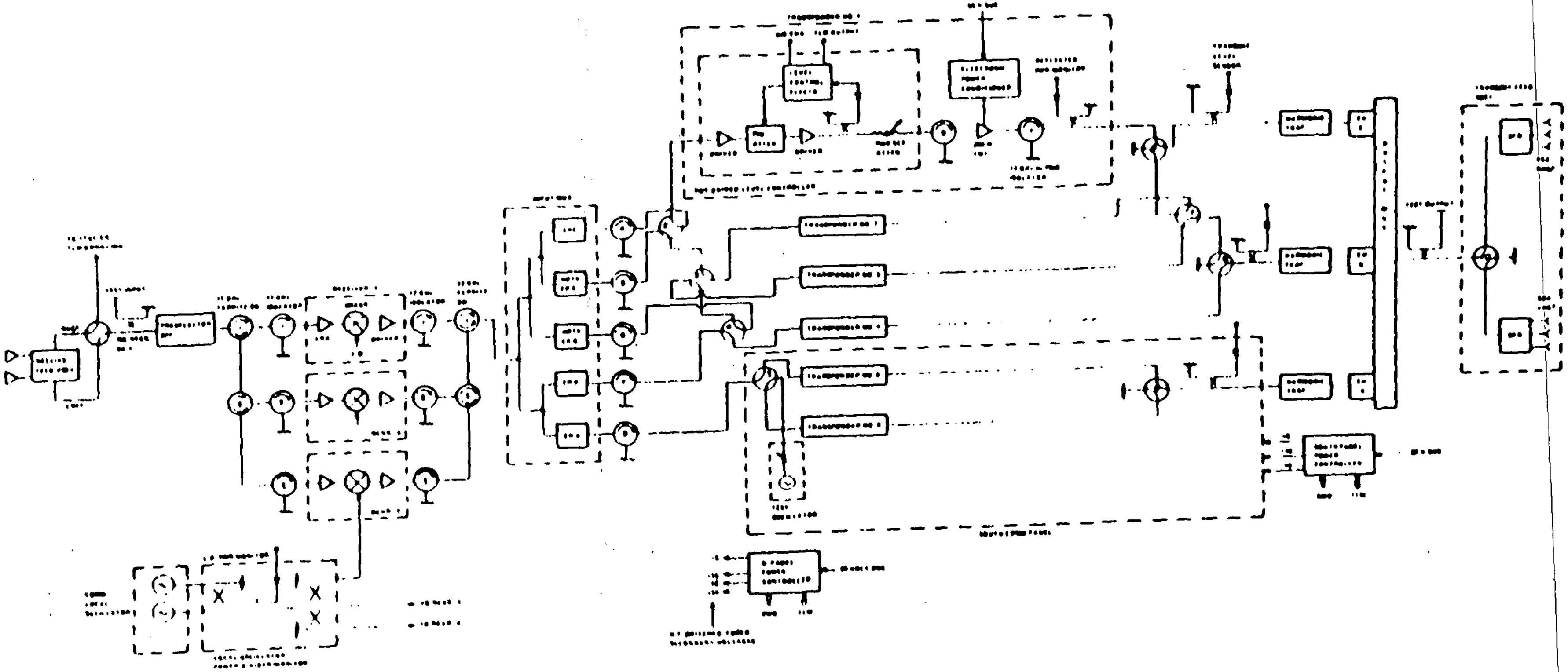
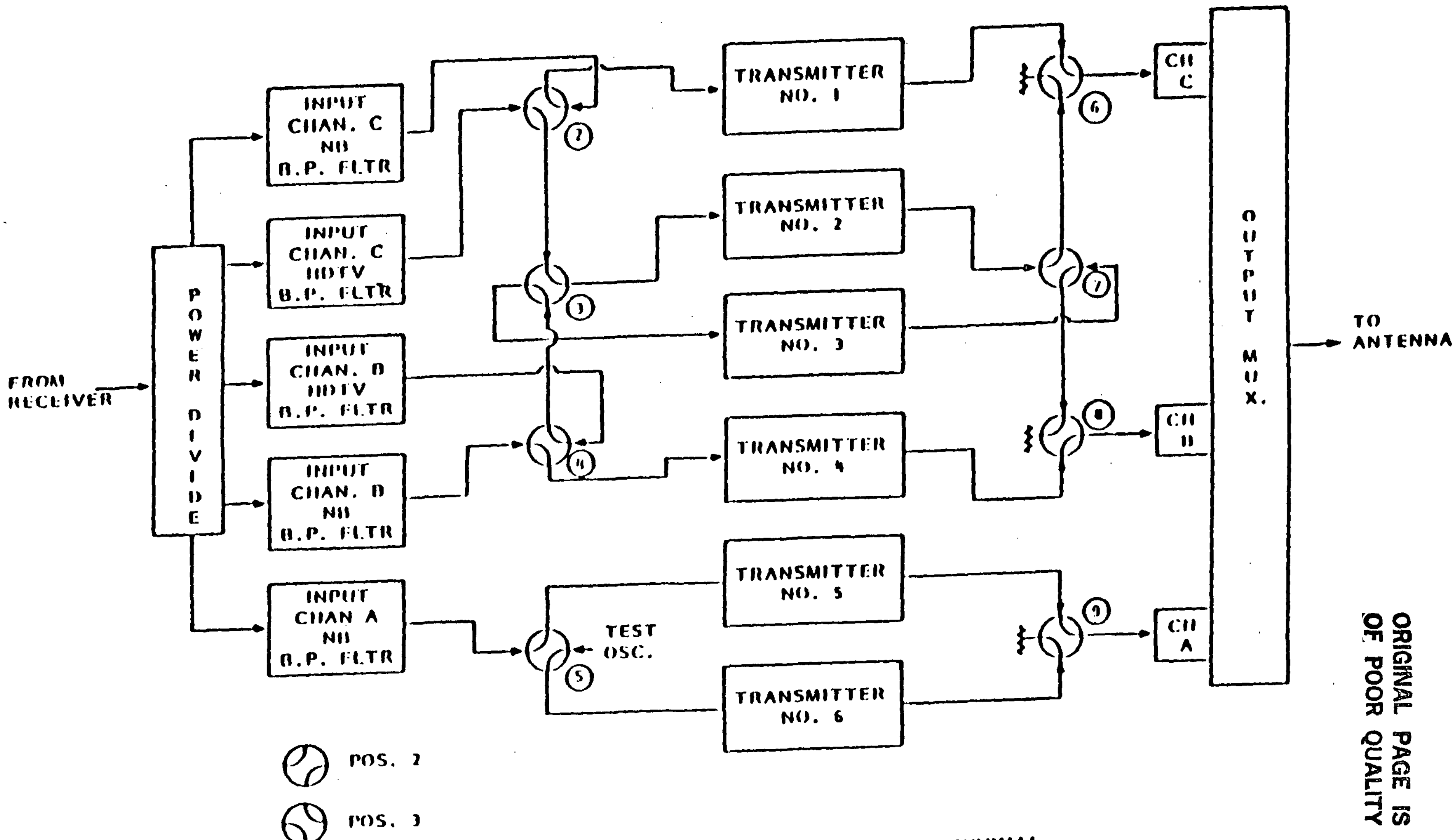


FIGURE 5.13 COMMUNICATIONS BLOCK DIAGRAM (DBS)



NOTE: ALL SWITCHES SHOWN IN MODE 1 - NORMAL

FIGURE 5.14 TRANSMITTER SWITCHING MATRIX (DBS)

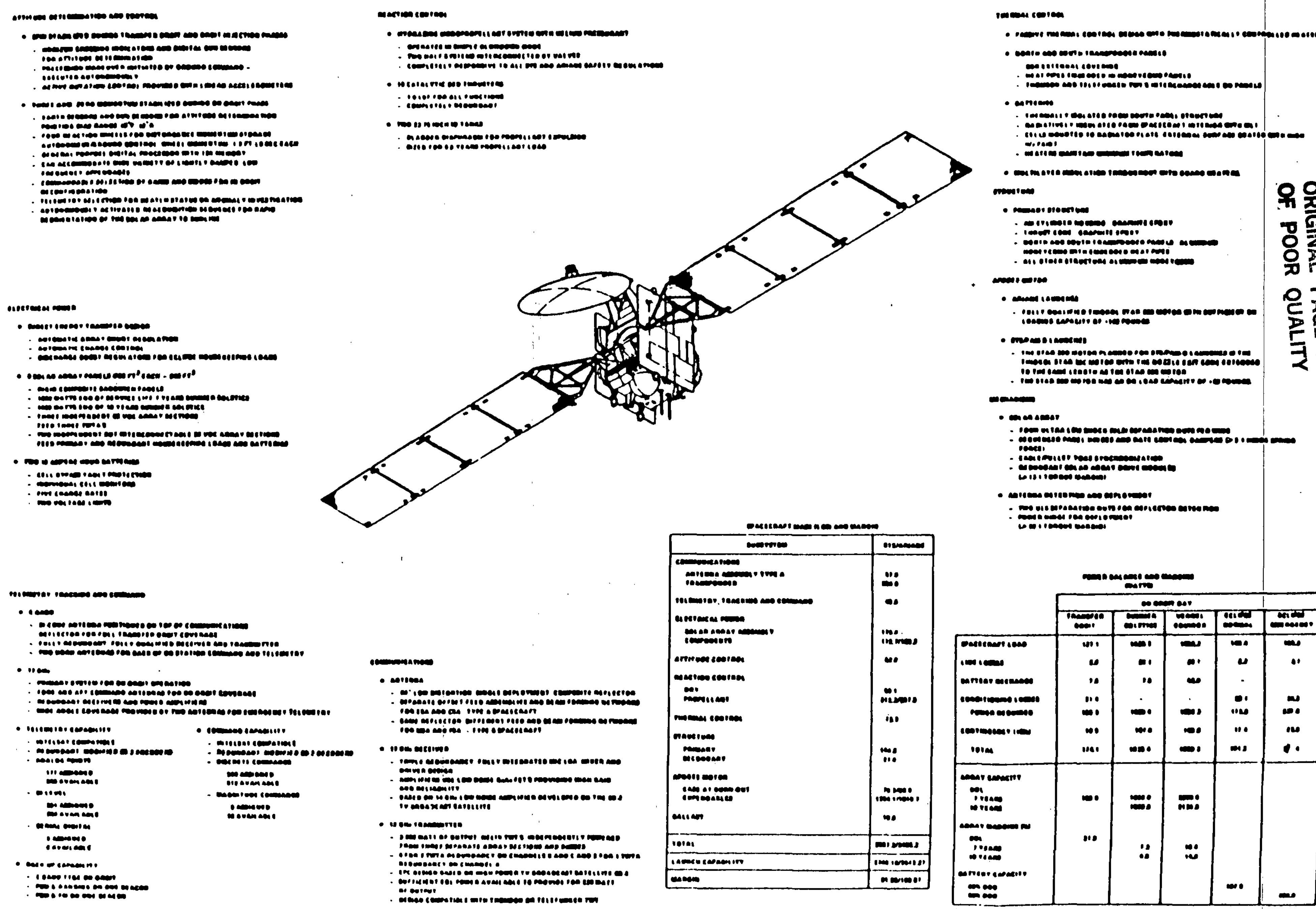


FIGURE 5.15 SPACECRAFT DESIGN FEATURES (DBS)

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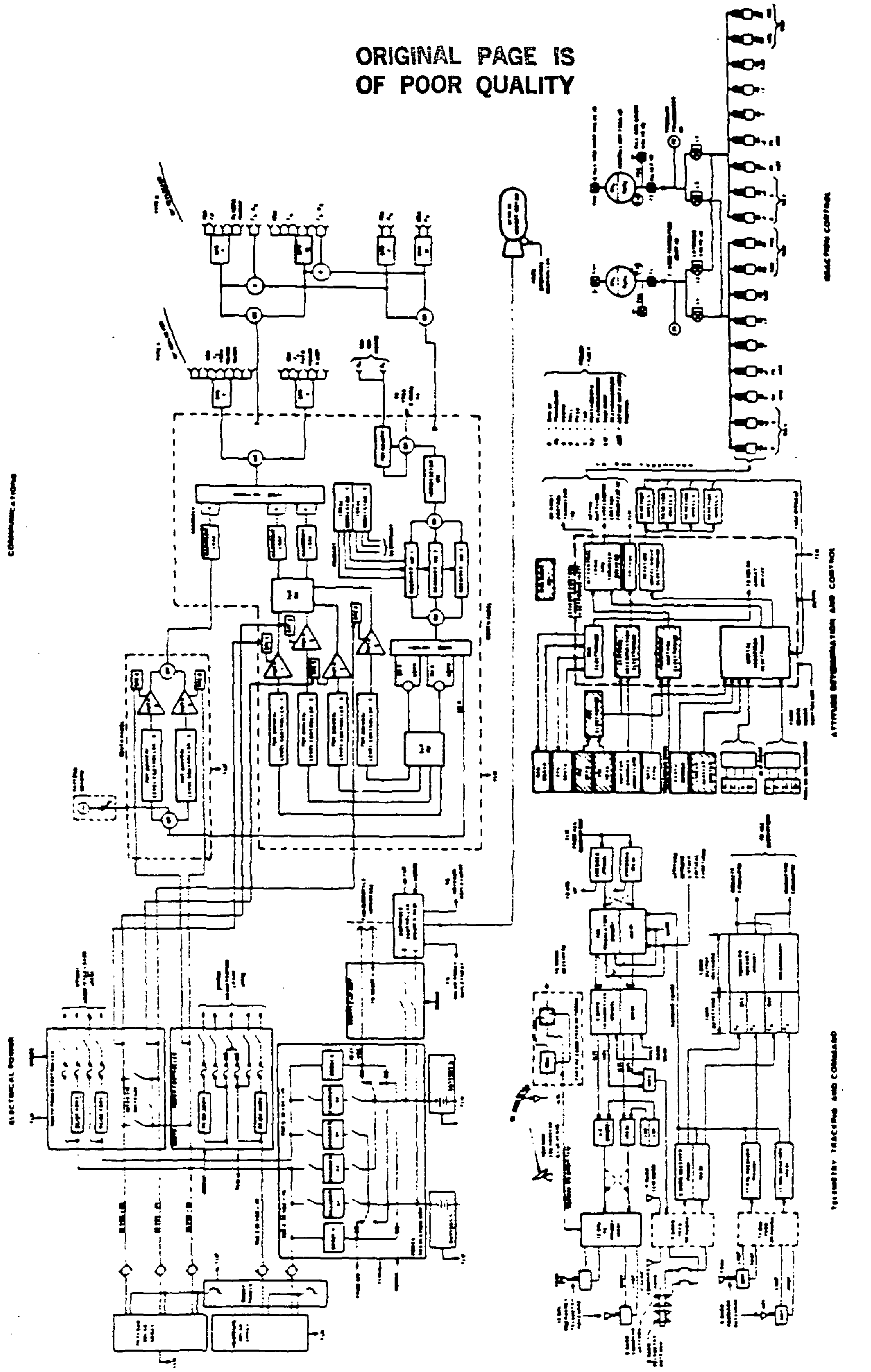

FIGURE 5.16 SPACECRAFT BLOCK DIAGRAM (DBS)

TWTAs and all input/output multiplexers and waveguide switches. In addition, the power controller for power switching and for secondary voltages is mounted on the north panel. Similarly, the smaller south panel supports two TWTAs and a power controller.

Electrical Power

The electrical power Subsystem (EPS) design provides separate solar array segments at 56 volt for operating each transponder channel, and dual 28 volt busses for spacecraft housekeeping equipment. This design is a straightforward approach to reliable broadcast operation that provides protection against a catastrophic power bus failure.

The major elements of the design are:

1. A solar array segmented for 56 volt transponder operation and 28 volt housekeeping functions.
2. A Power Regulation Unit containing battery chargers and boost discharge regulators for redundant housekeeping busses.
3. Two batteries rated at 12 ampere-hours each. Each contains a Battery Switching Unit (BSU) for detecting isolating faulty battery cells automatically or upon ground command.
4. A South Power Controller housing DC/DC converters and switches which distributes direct and conditioned power to load on the south equipment\panel.
5. A North Power Controller housing DC/DC converters and switches which distributes direct and conditioned power to load on the north equipment panel. This controller also provides the control and distribution for the transponder loads. It accomplishes load fault clearing and affords source paralleling modes for operation under degraded conditions.
6. An Ordnance Controller which operates on battery power directly and activates electroexplosive devices for solar array and antenna deployments.
7. A Shuttle Interface Unit (SIU) which prevents enabling of the Ordnance Controller until the DBS is safely deployed relative to the Shuttle.

Each 56 volt array segment is assigned to a transponder primary TWTA and its alternate. Using switches located in the

North Power Controller, the array sections may be inter-tied to operate any three of the six TWTAs. Under normal operation, the inter-ties remain disconnected to protect against source or load faults. Any such fault is thereby limited to one section permitting continued operation of the remaining transponder. No batteries are associated with the 56 volt payload power source and no fusing is used for fault protection. Since the 56 volt source is independent of the 28 volt housekeeping source, faults need not be cleared immediately for spacecraft survival. Instead, load faults may be cleared by ground command actuation of the power switch serving the faulty TWTA. The inter-tie switches also provide the means for extending mission life when each power source segment has degraded to the point where it can no longer support its' assigned load. With inter-tie closure, the combined output can support the load of two of the three broadcast channels. Similarly, two broadcast channels can be supported with inter-tie closure should solar array occulations resulting from lunar eclipse occur.

Power to each TWTA is ramped-on by a switch with transients limited by suppression circuitry contained in the EPCA. Turn-on is controlled by ground command. Turn-off before eclipse is also controlled by ground command with backup provided by an undervoltage cutoff. With turn-off, power is absorbed by thermostatically controlled heaters installed for each TWTA. Since no batteries are used in conjunction with payload power, the heaters may remain enabled through eclipse periods. Upon emergence from eclipse, all available solar energy is thereby utilized for warming up the TWTAs before broadcast service is re-

established.

Each 28 volt housekeeping bus is associated with a dedicated solar array segment, a partial shunt regulator, two charge regulators (main and back-up) and a boost discharge regulator. Loads are assigned equally to both housekeeping busses with each load function powered from one bus, and its active or inactive backup powered from the other bus. This is true of all housekeeping loads except momentum wheels and gyro which draw power from both busses through coupling diodes. Failure of one or the other housekeeping bus permits uninterrupted operation of critical functions during all mission phases.

Reaction Control

A mass expulsion hydrazine propulsion system with helium pressurant and all catalytic bed thrusters operating in blowdown (non-regulated) mode, is used for the baseline spacecraft.

Sufficient propellant is provided to accomplish the spacecraft propulsive functions during a seven-year mission. The two propellant tanks will accommodate a total propellant load to provide for initial orbit attainment, North-South and East-West stationkeeping, and the attitude control functions for the required seven-year mission plus a margin of 20% more propellant than will be required for the on-station phase of the mission.

Propellant Budget

The DBS fuel allocation for the Reaction Control Subsystem is based on the following requirements:

1. Application of STC specified V for correction of booster related transfer orbit 3-sigma errors.

2. Performance of the transfer orbit precession to re-orient the S/C out of the transfer orbit injection attitude into the AM firing attitude.
3. Performance of the post AM burn despin maneuver.
4. Performance of the drift orbit precession to point the spacecraft spin axis normal to the orbit plane.
5. Performance of 3-axis stabilization and post 3-axis stabilization maneuvers.
6. Maintenance of orbit and attitude to specified limits over the 7-year design life. Orbit maintenance requires east-west north-south stationkeeping to ± 0.1 degrees, while attitude maintenance requires torque control during stationkeeping maneuvers and periodic momentum wheel loading with thrusting.
7. Allowance for 1 repositioning of the spacecraft.
8. Compensation for uncertainties in propellant loading and weighing, residual fuel in the lines, expulsion capabilities of the tanks, thruster coupling and performance.

Figure 5.17 illustrates the locations of each of the thrusters on the spacecraft while Figure 5.18 summarizes the manner in which each thruster can be utilized for the various maneuvers. The thruster location and groupings have been selected to provide the required orbit maneuvers while maintaining complete redundant operational capability with no single-point failure capable of stopping the mission. Moment arms, subsystem packaging and minimum thruster plume impingement are other factors that have also been considered in the thruster locations.

The nine thrusters in each group operate at a maximum initial level of 4.45N. These thrusters provide the spacecraft with North-South and East-West orbit adjustment and three-axis attitude control during vehicle body stabilized operation. Pairs of thrusters are selectively matched to a 1.6% thrust variation band in order to minimize the thrust induced spacecraft disturbance torques which the Attitude Control Subsystem (ACS) must control.

Average thrust efficiencies used in the determination of the fuel allocation are summarized in Table 5.11. Also included in this table are the causes of performance degradation for each maneuver and its associated thruster. The fuel breakdown is given in Figure 5.19.

TABLE 5.11 AVERAGE THRUST EFFICIENCIES

Maneuver	Primary Thruster Number	Average Thrust Efficiency	Basis
Active Nutation Control	3 and 4	0.880	Pulsing, Rotation, Thruster Location, Plume Impingement
Precession (pre-Motor Burn)	3 and 4	0.890	Pulsing, Rotation, Thruster Location, Plume Impingement
Precession (Post-Motor Burn)	3 and 4	0.706	
Despin	1	0.985	Cant Angle
Initial Attitude Acquisition	1 to 6	0.732	Pulsing
Station Acquisition	15 and 16 or 13	0.994	Thruster Location, Plume Impingement
North/South Stationkeeping	1 and 2	0.926	Cant Angle, Plume Impingement, Non-Impulsive Maneuver
East/West Stationkeeping	15 and 16	0.994	Thruster Location, Plume Impingement
Longitude Repositioning	15 and 16	0.994	Thruster Location, Plume Impingement
Momentum Unloading	1 to 6	0.437	Pulsing
Torque Removal	1 to 6	0.722	Pulsing

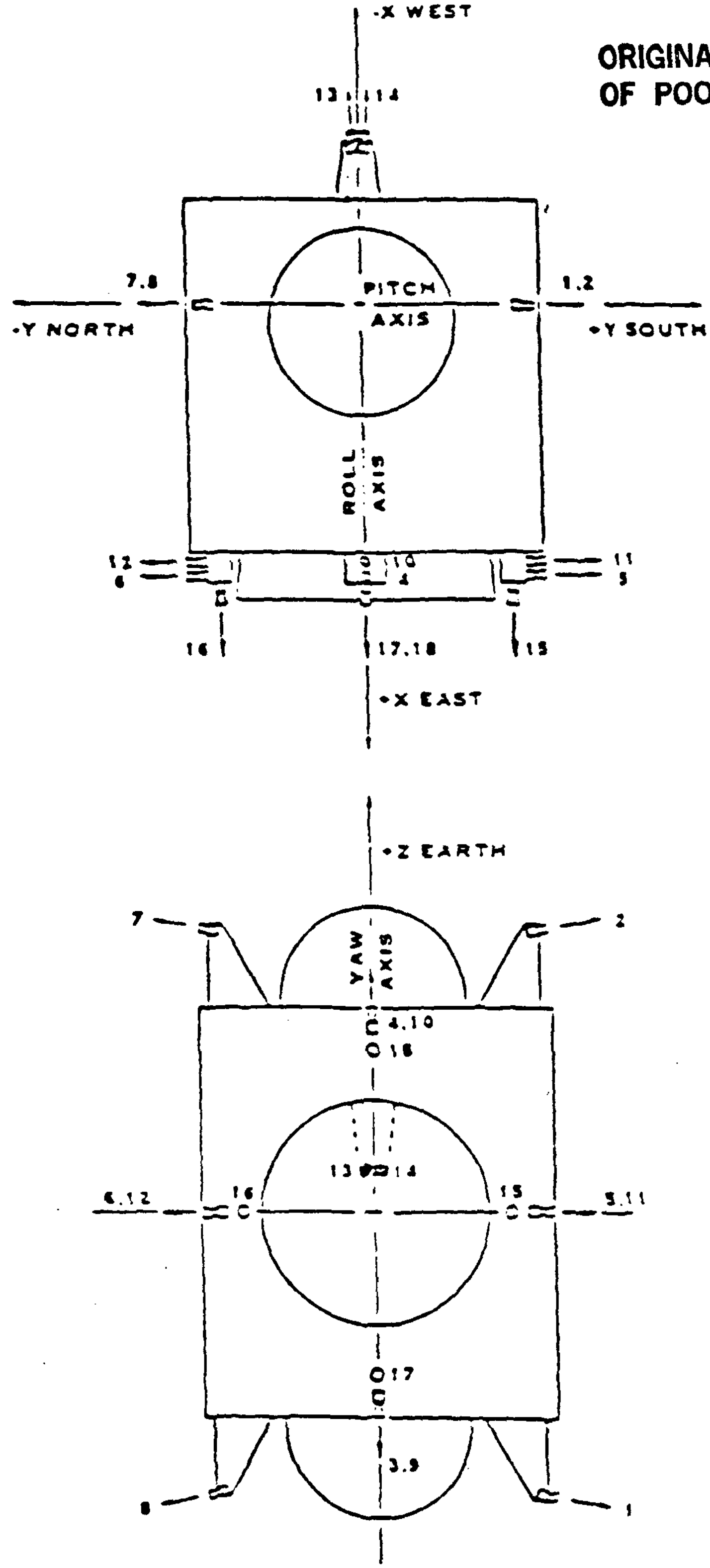

FIGURE 5.17 THRUSTER ARRANGEMENT (DBS)

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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SPIN CONTROL	X	X					X	X										
NUTATION CONTROL			X	X					X	X					X	X	X	X
PRECESSION			X	X					X	X					X	X	X	X
+ YAW CONTROL						X						X						
- YAW CONTROL					X						X							
+ ROLL CONTROL		X						X										
- ROLL CONTROL	X						X											
+ PITCH CONTROL				X						X								
- PITCH CONTROL			X						X									
NORTH INCLINATION CHANGE (1)	P_1 X	P_1 X																
SOUTH INCLINATION CHANGE (1)							P_2 X	P_2 X										
EAST STATION KEEPING STATION CHANGE													X	X				
WEST STATION KEEPING STATION CHANGE															P_3 X	P_3 X	P_4 X	P_4 X

P DENOTES OPERATION IN PAIRS

(1) INCLINATION CHANGE CAN BE ACHIEVED ENTIRELY WITH EITHER NORTH PAIR OR SOUTH PAIR THUS REDUNDANT CAPABILITY EXISTS

FIGURE 5.18 THRUSTER UTILIZATION (DBS)

MANEUVER	SPACE-CRAFT WEIGHT (KG)	ΔV REQUIREMENT (MPS)	REQUIRED SPACECRAFT IMPULSE (N·SEC)	$\bar{X}$ SPECIFIC IMPULSE (N·SEC/KG)	EFFECTIVE* AVERAGE SPECIFIC IMPULSE (N·SEC/KG)	PROPELLANT CONSUMED (KG)	INITIAL TANK PRESSURE (N/CM²)	FINAL TANK PRESSURE (N/CM²)
SPIN RATE INCREASE	1,247.5	-	0	2,292.0	-	0.00	236.0	236.0
ACTIVE NUTATION CONTROL	1,247.1	-	267.0	2,292.0	2,017.0	0.13	236.0	236.0
PRECESSION (PRE-MOTOR BURN)	1,247.0	-	7,694.0	2,291.6	1,987.0	3.87	236.0	224.8
PRECESSION (POST-MOTOR BURN)	674.2	-	481.0	2,288.1	1,615.4	0.29	224.8	224.0
DESPIN	673.9	-	2,080.0	2,287.8	2,253.5	0.92	224.0	221.7
INITIAL ATTITUDE ACQUISITION	673.0	-	267.0	2,288.8	1,674.0	0.16	221.7	221.2
STATION ACQUISITION	672.8	73.0	48,348.7	2,288.7	2,273.0	21.27	221.2	
N/S STATION-KEEPING	651.6	347.5	207,258.2	2,264.9	2,097.9	98.82		
E/W STATION-KEEPING	552.8	21.3	11,287.0	2,198.3	2,185.1	5.17		
LONGITUDE REPOSITIONING	547.6	18.3	9,605.2	2,196.2	2,183.0	4.40		
MOMENTUM DUMPING	543.2	-	3,088.0	2,194.4	980.0	3.08		
ΔV TORQUE REMOVAL	540.1	-	3,724.0	2,193.2	1,587.5	2.23		86.0
MISSION TOTAL	-	460.1	294,066.1	-	-	140.34	-	-

*ACCOUNTS FOR THRUST INEFFICIENCY

**AKM CONSUMED WEIGHT = 568.9 KG

FIGURE 5.19 PROPELLANT BUDGET - STS/PAM-D

5.3.2 Ion Propulsion Impact

The baseline Direct Broadcast Satellite presented above has been modified to include the use of ion propulsion for NSSK using NASA technology. Foreign technology is also reviewed and the differences are discussed later. The ion propulsion system selected for NSSK of this size spacecraft uses inert gas such as xenon. Its duty cycle of usage is assumed to be three hours a day on the average. A single thruster is assumed to be used with a backup thruster on the spacecraft. The NSSK requirement represents an average velocity increment of 45.8 m/s/yr. This represents an average acceleration of 1.45×10^{-6} m/s^2. The DBS spacecraft is assumed to have a BOL mass in orbit of 625 kg. This leads to a daily impulse requirement of 78.4 N-S.

In order to use the thruster effectively two effects must be accounted for. The thruster will be canted away from the solar arrays for the non-spinning DBS, up to an angle of 30 degrees. This is accounted for by assuming a loss of effectiveness of 13.4% due to either canting or plume impingement. In addition to this, the three-hour thrust interval requires that some non-ideal impulse be applied as the spacecraft moves around the orbit. Thus, the thrust effectiveness, due to a finite burn time of three hours is calculated to be 97.45%. Combining these two factors leads to an overall thrust effectiveness of 84.39%. Therefore, the total equivalent daily impulse required of the thruster is 92.9% N-S. This leads to a thrust level over a 3-hour period per day of 8.6 mN. Using a 7-year life for this DBS mission, several factors have been developed that are associated with the design of the subsystem.

The important design parameters that were derived based on the above assumptions are as follows. The beam current is 0.18 amperes with a specific impulse of 2,926 seconds. This leads to an acceleration voltage of 923.9 volts and a power requirement of 276.6 watts. The propellant load for 7 years is calculated to be 8.23 kg. The power processor mass is calculated to be 5.54 kg and the thruster mass is 4.56 kg per thruster. In addition to this, a tank is needed to hold the xenon. Assuming a 5% margin of xenon mass which gives a total propellant mass of 8.64 kg, the volume of the required tank at 75°F in a 4200 PSIG is 520.3 cubic centimeters. This gives a spherical tank of radius 9.3 centimeters and a mass of roughly 3 kg.

The amount of hydrazine allotted for NSSK in the baseline DBS propellant budget is 98.8 kg. Thus, there is a significant potential savings in terms of overall spacecraft mass, which could be used in other areas. The total differential savings between the elimination of the hydrazine for NSSK and the addition of the xenon is approximately 90 kg. In addition to this there is the added savings of smaller propellant tanks for hydrazine. The dry ion-thruster system adds about 19 kg of mass (including plumbing and harnesses). The electric power system components are about 52 kg heavier with the ion-thruster. There is thus a net mass savings of 28 kg for the use of ion propulsion. This assumes that the baseline battery capacity and solar arrays can handle the application of ion propulsion with a duty cycle that would be sufficient to maintain orbital control. If this in not the case, additional batteries and solar cells may have to be added or committed to the ion-thruster system. If the

margin is reduced by about 22 kg then 50 kg of mass is available to be put into one extra channel and two additional years of life.

Foreign competition was discussed in Section 4.3.1 and 5.2.2.

5.3.3 Solar Cell Impact

The effect of new solar cell technology on DBS was evaluated by simply increasing the cell efficiency from 13% to 18% and making the appropriate adjustments in solar array size, structural mass, thermal requirements, etc. The results indicate some improvement in payload utilization and reduced spacecraft mass.

5.3.4 Point Design with Improvements

As with the fixed services satellite, two point designs of DBS satellites were developed, one which includes improved solar cells and the other an ion propulsion NSSK system. Table 5.12 summarizes the mass breakdown for the baseline DBS, the DBS using Gallium Arsenide solar cells and the DBS using ion-thrusters. A mass summary is provided for both reduced mass and extended capability for the Gallium Arsenide solar cells design and the ion thruster design. The extended capability satellite using the Gallium Arsenide technology is designed with an additional two years of life. An additional channel and an additional two years of life is designed into the extended capability ion-thruster satellite.

TABLE 5.12 MASS SUMMARY OF IMPROVED DBS SATELLITE (KG)

Subsystem	Baseline	With GaAs Reduced Mass	With GaAs Extended Capability*	With Ion NSSK Reduced Mass	With Ion NSSK Extended Capability+
Communications					
Antenna	26.3	26.3	26.3	26.3	26.3
Repeater	92.5	92.5	92.5	92.5	120.4
T T & C	22.0	22.0	22.0	22.0	22.0
ACS	23.9	23.9	23.9	23.9	23.9
RCS (Hydrazine)	26.3	26.3	26.3	18.4	18.5
Ion NSSK				18.3	18.3
EPS					
Solar Array Assembly	79.5	66.6	66.6	79.5	93.8
Components	78.3	78.3	78.3	130.5	130.5
TCS	33.2	33.2	33.2	33.2	34.0
Structure	78.0	78.0	78.0	78.0	79.4
AKM Case	34.6	34.6	34.6	34.6	34.6
Balance Mass	4.5	4.5	4.5	4.5	4.5
EOM Mass	499.1	486.2	486.2	561.7	606.2
Mission N2H4	140.3	140.3	168.7	41.4	44.4
He Pressurant	.1	.1	.1	.1	.1
Xenon Load	0.0	0.0	0.0	8.2	10.6
Satellite Lift-off mass -	639.5	626.6	655.0	611.4	661.3
Design Margin	42.3	42.3	26.9	42.3	20.7
Satellite Lift-off Mass Plus Design Margin	681.8	668.9	681.9	653.7	682.0

* With two additional years
\+ With one additional channels and two additional years
\- exclusive of PAM-D, cradle or apogee kick motor propellant mass

5.4 Cost Analysis

The objective of the cost analysis was to derive valid and comparable estimates on the price, to communications satellite operators, of satellites using various levels of technology. The analysis was separated into two segments; acquisition costs and launch costs. Each of these analyses is discussed in following paragraphs.

The cost to a communications satellite operator of acquiring new (or additional) satellites includes nonrecurring costs to develop or modify the vehicle, and recurring costs to produce and support the flight units. A general-case parametric cost-prediction model, PRICE 'H' developed by RCA was used to estimate all acquisition costs. The analysis was performed in two steps:

* The cost of two reference or base case satellites (a Direct Broadcast Satellite and a Fixed Services Satellite) were modeled. The estimated costs to the manufacturers against representative sales prices for such satellites were calibrated to obtain markup factors.

* The costs of the same satellites when they incorporate important new technologies were estimated. The derived markup factors were applied to obtain a new price to the communication satellite users.

Ground rules and assumptions used in the analysis are as follows:

* All costs are expressed in constant 1985 dollars (January 1 economic conditions).

* No full-system test articles are produced; however, at subsystem and component-level, test articles are assumed for the new-technology hardware.

* It is assumed that the new technologies will have completed a feasibility demonstration phase at NASA before being released to the builders. This implies that although the subsystem design and technology would be new to these contractors, there would be no major unknowns that would require multiple development paths. It also means that new hardware will have to be sized to specific satellite applications and fully qualified for flight use.

Price 'H' is a general-case hardware cost-prediction model. The term 'general case' means that the model is, in fact, a simulation of the forces that drive cost (e.g. size, complexity, schedule) and is not based on specific, historically-derived cost estimating relationships. Special case models estimate costs for narrow product lines. A general case hardware model can estimate the cost of any manufactured product, provided that the model is given a technical and programmatic description of the product, and provided that the model variables have been calibrated to that product.

Specific questions, the responses to which form the input data set for the Price 'H' model are as follows:

* What is the product? Is it an electronic item, a structure or a mechanism? Is it built to commercial or Government specifications? If Government, must the item operate in difficult environments such as ground-mobile, shipboard, airborne or space?

* How complex is it? This is a set of variables that can be calibrated in several different ways as described subsequently.

* How big is it? What is unit weight? If an electronic item, how much of total weight is electronics?

* How many will be built? What is the total quantity of items in production? How many equivalent units (fractions acceptable) are to be built as test articles?

* How new is the product? Has this firm ever produced a similar item? If so, what fraction of drawings exist? Has any such thing ever been built? Is the state of the art beyond current capability, such that multiple and independent development paths must be followed?

* When is it needed? Are the development schedules defined? If so, what are start and end dates and key milestones? Is the production schedule defined? Are there breaks in the lot buys?

* How is it produced? What mechanical processes are involved: casting, machining, sheet metal fab? How

automated are these processes? Is the product monolithic or built-up? How automated are electronic fabrication processes?

* How is the item integrated into higher-level assemblies? Are special alignments required? Are special tests required at higher levels? Do the electronics require extensive calibration?

Using these inputs, the Price 'H' model can estimate development and production-phase costs at component or assembly level and can then project the integration/assembly/test costs at subsystem and higher levels. However, the validity of the costs so estimated by Price depends in large measure on the accuracy with which the driving complexity varibles have been calibrated.

The most significant variable in Price 'H' is the inherent-complexity factor for structural/mechanical items, and for electronic circuitry. There are three ways to obtain this variable:

- Calibration: Running Price 'H' with historical cost data to extract this variable.
- Analytical Formulations: Using RCA derived or approved equations to predict the complexity factors.
- Table Lookup: Using RCA-supplied tables of complexity factors for similar products. Cost research has shown that the electronics-complexity tables are far more reliable than the structural/mechanical-complexity tables.

Regardless of which method is used to select the complexity factors, the resulting cost estimates must be calibrated in terms of their consistency with the relative costs, sizes and complexities of similar products.

The FSS and DBS development and production costs were estimated at component level so as to incorporate the new-technology subsystems and also to measure the effect of these advanced technologies on the payload subsystems. Equipment

lists, weights and quantities for each configuration of each satellite were input to the RCA PRICE model. Complexity factors, based on historical cost data, were also input to PRICE. The resulting estimates predicted the cost to the satellite producer of developing and manufacturing one vehicle of the configuration defined. Learning factors for quantities greater than one were derived using parametric PRICE model runs for multiple-unit lost and deriving gross learning slopes to approximate the cost/quantity relationship.

The resulting cost estimates for typical FSS and DBS satellites are given in Tables 5.13 and 5.14. These tables show the nonrecurring (DDT&E) and unit-recurring costs for each type of satellite:

* Baseline: Current technology with heavy design inheritance from existing communications satellites.

* Gallium Arsenide (GaAs) Solar Cell Technology: The baseline (current technology) satellite modified to incorporate overall mass savings that can be achieved with GaAs cells. These mass savings are converted into additional payload capability.

* Ion Propulsion Technology: The baseline satellite modified to incorporate the mass savings attainable with ion propulsion technology. These mass savings are converted into additional payload capability.

The estimated costs for each satellite are summed and an estimated manufacturer's markup is applied to all costs to arrive at a selling price to the communications satellite operator.

The launch costs for delivering the various communications satellite concepts to synchronous-transfer orbit were derived using the most current understanding of space-transportation standard charges. These costs were all normalized to 1985

dollars for consistency with the acquisition costs.

The user charge for Shuttle transportatioon to low-earth orbit was computed using NASA's weight/length formula and was based on a dedicated-flight price of $71 million (1982 dollars) which is valid for 1986-88 launches. The calculation of STS user charges is illustrated in Figure 5.20. To this figure was added the user charge for a PAM-D upper stage to deliver satellites from low orbit to geosynchronous-transfer orbit. This is $5.6 million in 1985 dollars.

TABLE 5.13 FIXED SERVICES SATELLITE COST AND PRICE SUMMARY

	BASELINE		WITH GaAs SOLAR CELLS		WITH ION PROPULSION	
	NR	R	NR	R	NR	R
ANTENNA	691	1,749	691	1,749	691	1,749
TRANSPONDERS	1,945	4,348	3,194	4,601	3,346	4,827
SUBTOTAL PAYLOAD	(2,636)	(6,097)	(3,885)	(6,350)	(4,037)	(6,676)
TT&C	1,900	3,672	1,900	3,672	1,900	3,672
EPS	1,916	3,512	4,858	3,375	2,522	3,962
ACS	947	1,929	947	1,929	947	1,929
RCS	274	838	274	838	588	779
ION PROPULSION					7,313	1,589
STRUCT/THERMAL	736	1,532	736	1,532	736	1,532
AKM	119	193	119	193	119	193
SUBTOTAL HARDWARE	(5,892)	(11,676)	(8,834)	(11,539)	(14,125)	(13,656)
SOFTWARE	—	—	—	—	—	—
TOTAL END ITEMS	(8,528)	(17,773)	(12,719)	(17,889)	(18,162)	(20,232)
SYSTEMS*	6,311	9,775	9,412	9,839	13,440	11,128
GRAND TOTAL	(14,839)	(27,548)	(22,131)	(27,728)	(31,602)	(31,360)
PRICE	(20,775)	(38,567)	(30,983)	(38,819)	(44,243)	(43,903)

*INCLUDES ALL SYSTEM-LEVEL ACTIVITIES, I.E. FINAL ASSY., PROGRAM MANAGEMENT, SYSTEMS ENGR./INTEGRATION, SYSTEMS TEST, RELIABILITY/QUALITY.

TABLE 5.14 DIRECT BROADCAST SATELLITE COST AND PRICE SUMMARY

	BASELINE		WITH GaAs SOLAR CELLS		WITH ION PROPULSION	
	NR	R	NR	R	NR	R
ANTENNA	573	1,523	573	1,523	573	1,523
TRANSPONDERS	2,333	4,645	2,333	4,645	4,042	5,366
SUBTOTAL PAYLOAD	(2,906)	(6,168)	(2,906)	(6,168)	(4,615)	(6,889)
TT&C	1,982	4,008	1,982	4,008	1,982	4,008
EPS	2,584	5,157	4,159	4,788	3,893	6,168
ACS	964	2,694	964	2,694	964	2,694
RCS	407	1,554	407	1,554	407	1,554
ION PROPULSION					7,313	1,589
STRUCT/THERMAL	874	1,781	874	1,781	874	1,781
AKM	129	210	129	210	129	210
SUBTOTAL HARDWARE	(6,940)	(15,404)	(8,515)	(15,035)	(15,562)	(18,004)
SOFTWARE	1,609	—	1,609	—	1,609	—
TOTAL END ITEMS	(11,455)	(21,572)	(13,030)	(21,203)	(21,786)	(24,893)
SYSTEMS*	8,477	11,865	9,642	11,662	(16,122)	(13,691)
GRAND TOTAL	19,932	33,437	22,672	32,865	37,908	38,584
PRICE	39,864	66,874	45,344	65,730	75,816	77,168

*INCLUDES ALL SYSTEM-LEVEL ACTIVITIES, I.E. FINAL ASSY., PROGRAM MANAGEMENT, SYSTEMS ENGR./INTEGRATION, SYSTEMS TEST, RELIABILITY/QUALITY.

ORIGINAL PAGE IS OF POOR QUALITY

SHARED SHUTTLE FLIGHT PRICE ESTIMATE

PAYLOAD FIXED SERVICES SATELLITE   LAUNCH DATE SEPTEMBER 1988

OPTIONAL SERVICE 1 PAM-D OPTIONAL SERVICES PACKAGE • SHUTTLE LAUNCHES FY86 - FY88
PRICE • .136 (1984)

OPTIONAL SERVICE 2 PAM-D AMORTIZATION CHARGE • SHUTTLE LAUNCHES FY83 - FY88
PRICE • .0350 (FY)

PAYLOAD CHARGE FACTOR CALCULATION

LOAD FACTOR (WEIGHT) • CONTROL WEIGHT, LBS / SHUTTLE CAPABILITY • 7846 / 65000 • .151

LOAD FACTOR (LENGTH) • CONTROL LENGTH, IN. / 60 x 12 • 98 / 720 • .136

CHARGE FACTOR • LARGER LOAD FACTOR / .75 • .151 / .75 • .201

STANDARD SHARED FLIGHT PRICE • .201 • 14.271 (1982)

BOOKING DATE IS ASSUMED TO BE 33 MONTHS PRIOR TO DESIRED LAUNCH DATE
PROGRESS PAYMENT ACCELERATED SCHEDULE BEGINS 30 MONTHS BEFORE LAUNCH (IN MILLIONS OF US DOLLARS)

DUE DATE	%	STANDARD SERVICES $ 1982 $	ESCALATION FACTOR*	$ REAL YEAR $
EARNEST MONEY		.000		.000
SEP 86	10	1.620	1.221	1.742
JUNE 87	20	3.239	1.329	3.793
DEC 87	35	5.669	1.376	6.873
SEP 88	35	5.669	1.434	7.263
LAUNCH SEP 88	100	16.198	TOTAL STANDARD SERVICES:	19.671
			TOTAL OPTIONAL SERVICES:	.278
			TOTAL SHARED FLIGHT PRICE (REAL YEAR $):	19.949

DUE DATE	OPTIONAL SERVICES $ 1982 $	ESCALATION FACTOR*	$ REAL YEAR $
DEC 87	.227	1.376	.278
TOTAL OPTIONAL SERVICES	.227		.278

* [illegible] PROJECTED ESCALATION FACTORS [illegible] LONG TERM FACTORS [illegible] [illegible] AUGUST 31, 1984 — [illegible] REPORT [illegible]
[illegible] SHUTTLE [illegible] FLIGHT PRICE - [illegible] (1982) EFFECTIVE OCT 1985 THRU SEP 1988)   [illegible]

FIGURE 5.20 STS USER CHARGE CALCULATION

6.1 Fixed Satellite Services Scenarios

A typical but hypothetical fixed satellite services business venture was planned to serve as a baseline case. The postulated venture represents a carrier that launches and operates satellites with the objective of generating revenue through the leasing of transponders. The venture does not participate in the broadcasting or transmission of data. The baseline spacecraft is a spin stabilized satellite that transmits in the Ku frequency band, based on the H376 model described in Section 5. The satellite has a 20 for 16 redundancy, with 16 active transponders and 4 spare transponders. This particular business is based upon placing and maintaining three operational satellites in orbit. The first satellite will be launched midway through the fourth year, and the second and third midway through years five and seven. Satellites that fail or wear out will be replaced subject to a launch delay (between .5 and .8 of a year) and three months delay to allow for transit from LEO to GEO and on-orbit testing and check-out. The business will utilize the Space Shuttle for launching the satellites, and will relaunch when the number of active transponders (in a satellite) falls below fifteen. On each satellite, up to 14 transponders will be made available for lease as protected service and up to 2 as unprotected at a price less than half that of the protected transponders. Protected and unprotected services are defined in Section 2.

Data descriptive of the baseline business scenario for a fifteen year period was established and entered into the data base. The data base is presented in Appendix C and consists of reliability and systems data (associated with the satellite and the launch vehicle), cost data (satellite unit and nonrecurring cost, launch costs, business expenses, and capital costs), financial data (such as tax rate, interest rate, depreciation life, receivables, etc.), market data such as demand for transponders, price and price elasticity, and decision data points such as transponder relaunch threshold.

The data were obtained in several ways. Spacecraft were configured and the appropriate spacecraft parameters were used with the RCA PRICE model (described in Section 2) to derive the spacecraft unit recurring and nonrecurring costs, which were entered into the DOMSAT data base. Appropriate Spacecraft attributes from the developed configurations were also entered into the data base (for instance, number of transponders, transponders groupings, and reliability parameters). Conversations with several carriers helped form the business scenario by revealing sparing concepts, decisions that might be made with regard to the use of spacecraft mass savings, and the format of the financial statements used by carriers. Operating costs, capital costs and financial data were obtained from FCC filings and annual reports of the carriers. Market estimates were based on data from the FCC filings. Transponder pricing data was obtained through conversation with the carriers and current published tariffs for the same or similar services to that

postulated for the business scenario (see Tables 2.3 and 2.4).

The DOMSAT Model was then used to perform the financial analysis using the base case data. Financial results were generated for later comparison with the improved technology cases. The base case results are provided in Appendix C together with the base case data.

The spacecraft were reconfigured using the two improved technologies: ion-thrusters and Gallium Arsenide solar cells. Mass savings on the order of 90 kilograms resulted from the incorporation of the ion-thruster technology into the FSS satellite; mass savings of 15 kilograms resulted from the incorporation of the Gallium Arsenide technology into the FSS satellite. These mass savings allowed four additional active transponders and two years of life to be redesigned into the ion-thruster satellite and two additional active transponders into the Gallium Arsenide satellite. Extended capability was therefore designed into the satellites so that the mass at liftoff was approximately the same as the liftoff mass of the base case satellites. The data sets were then adjusted with the new parameters: new spacecraft nonrecurring and recurring costs, the number of transponders, and the on-orbit life. The parameters that were adjusted are displayed in Table 6.1 for each scenario. All other variables were held constant. The DOMSAT Model was then used to reanalyze the business scenario with the new parameters and the financial results (ROI, profit, net present value, etc.) were then compared with results produced from the base case scenario.

It was found that the nonrecurring costs associated with the development of a satellite utilizing the new technology was a major factor in establishing the financial attractiveness of the technology. Since it is possible that nonrecurring satellite costs may be recovered in different ways, several possible situations were analyzed. Each new technology case was analyzed with three different nonrecurring costs. One situation (referred to as the first user) considered that the full nonrecurring costs would be recovered from the first business purchasing the satellite containing the new technology (for example, ion-thrusters). A second situation (referred to as the later user) used the same nonrecurring costs as the base case to simulate a

TABLE 6.1 PARAMETERS THAT VARY WITH SCENARIO
FIXED SERVICE SATELLITE

	BASE CASE	ION-THRUSTER	GALLIUM ARSENIDE
NONRECURRING COST*			
MINIMUM	$19.8	$42.0	$29.4
EXPECTED VALUE	20.8	44.2	31.0
MAXIMUM	25.0	61.9	43.4
RECURRING COST*			
MINIMUM	36.4	41.3	36.5
EXPECTED VALUE	38.6	43.9	38.8
MAXIMUM	40.9	46.5	41.1
NUMBER OF ACTIVE TRANSPONDERS	16	20	18
LIFE (AVCS)**	8 YEARS	10 YEARS	8 YEARS

* MILLIONS OF 1985 DOLLARS
** EXPECTED WEAROUT LIFE OF ATTITUDE, VELOCITY AND CONTROL SYSTEM

user of the technology after many applications so that the improved technology satellite had been developed to the point that the base case satellite has been developed. A third situation (referred as the midpoint user) was considered as being mid-way between the first two situations. Thus, the sensitivity of the business venture to nonrecurring cost was considered. The results obtained indicate the importance of NASA pursuing technology programs through the satellite demonstration stage in order to speed the introduction of the results of the technology programs.

6.2 Fixed Satellite Services - Results

Several financial performance measures are considered when a firm considers making an investment. In this section profit, indebtedness, net present value and return on investment of the three scenarios (base case, ion-thruster and Gallium/Arsenide) are compared to gain insight into the likelihood that a private venture would invest in the improved technology satellites under the defined business scenarios.

Expected profit of each scenario is depicted in Table 6.2 and illustrated in Figure 6.1 for the first user of the improved technology. The ion-thruster scenario incurs the largest losses in the first four years as a result of the large increase in nonrecurring cost. All scenarios turn profitable in the fifth year. GaAs technology results in improved profit performance (relative to the base case) starting in the third year. Ion-thruster technology becomes more profitable than the base case in the eighth year and more profitable than GaAs technology in the

TABLE 6.2 FSS EXPECTED PROFIT - BASE CASE COMPARED WITH FIRST USER SCENARIOS (THOUSANDS OF 1985 $)

YEAR	EXPECTED PROFIT BASE CASE	EXPECTED PROFIT ION-THRUSTER	EXPECTED PROFIT GALLIUM ARSENIDE
1	(12324)	(10462)	(12922)
2	(5064)	(15879)	(11041)
3	(4686)	(10730)	(4080)
4	(2526)	(2573)	(1390)
5	24439	27319	26844
6	30766	30011	31941
7	38021	37067	39539
8	60060	64653	65583
9	64320	70082	71164
10	66072	70899	72550
11	68870	77092	77524
12	63728	81951	73981
13	60122	88608	70308
14	70289	93523	80948
15	70694	85160	82213

( ) INDICATES A LOSS

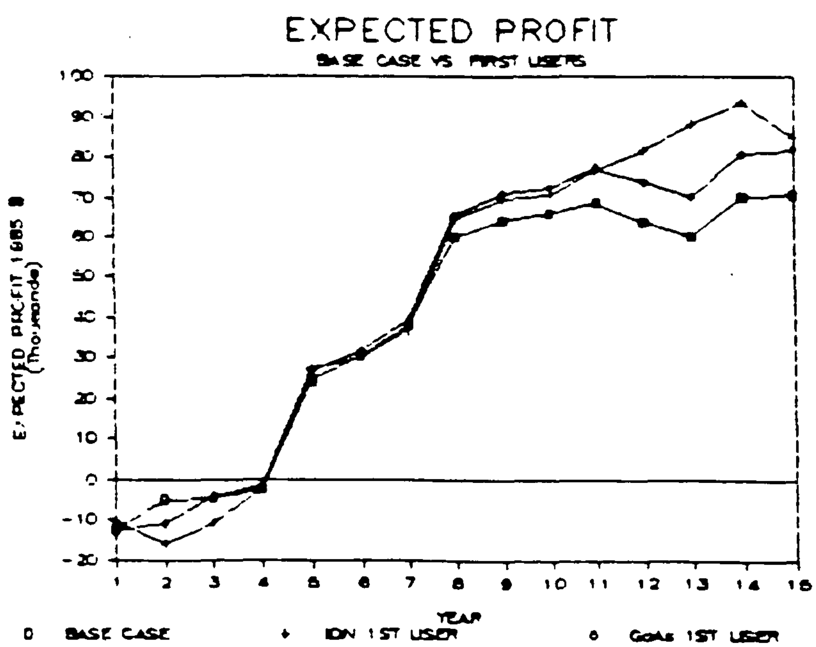

FIGURE 6.1 FSS EXPECTED PROFIT - BASE CASE COMPARED WITH FIRST USER SCENARIOS

twelfth year.

Results for the early years reflect the substantial increase in the nonrecurring costs associated with the new technology satellites (especially the ion-thruster satellite). In the later years, the enhanced capability (more transponders and/or longer life) of the new technology satellites have a positive effect on expected profit relative to the base case. Because of the increased capability, fewer satellite launches are required to maintain a given satellite capacity (due to increased life) and more transponders are available for revenue generation.

Similar factors are apparent in the expected indebtedness of each scenario (Table 6.3 and Figure 6.2). Payback occurs between the eighth and ninth years for the base case and GaAs scenarios, and between the ninth and tenth years for the ion-thruster scenario. Indebtedness under the GaAs scenario is less than the base case during almost the entire 15 year period (except the first year). The peak of indebtedness is over $4 million less for the GaAs scenario than for the base case scenario. Indebtedness of the ion-thruster scenario is higher than the base case until the eleventh year.

Comparison of the scenarios portraying later users of the technology (as mentioned above, the nonrecurring costs are set equal to the base case nonrecurring costs) reveals a distinctly more favorable outlook for the new technology cases. Over the entire time horizon considered (except the first two years), profits are higher (and losses lower) for both new technology scenarios compared with the base case scenario. In the latter years the differences are greater because of the extended

TABLE 6.3 PSS EXPECTED INDEBTEDNESS
BASE CASE COMPARED WITH FIRST USER SCENARIOS
(THOUSANDS OF 1985 $)

YEAR	EXPECTED INDEBTEDNESS BASE CASE	EXPECTED INDEBTEDNESS ION-THRUSTER	EXPECTED INDEBTEDNESS GaAs SOLAR CELLS
1	11014	9350	11549
2	42642	42925	34750
3	110872	113366	91339
4	168545	186057	160104
5	179411	202042	175065
6	170589	194133	165162
7	142323	171441	140257
8	77454	102814	70809
9	(1789)	15644	(16460)
10	(83143)	(74358)	(106727)
11	(160122)	(169188)	(196217)
12	(221992)	(269932)	(272038)
13	(280519)	(377146)	(338122)
14	(358298)	(486657)	(421174)
15	(446913)	(588226)	(518876)

( ) INDICATES NEGATIVE INDEBTEDNESS

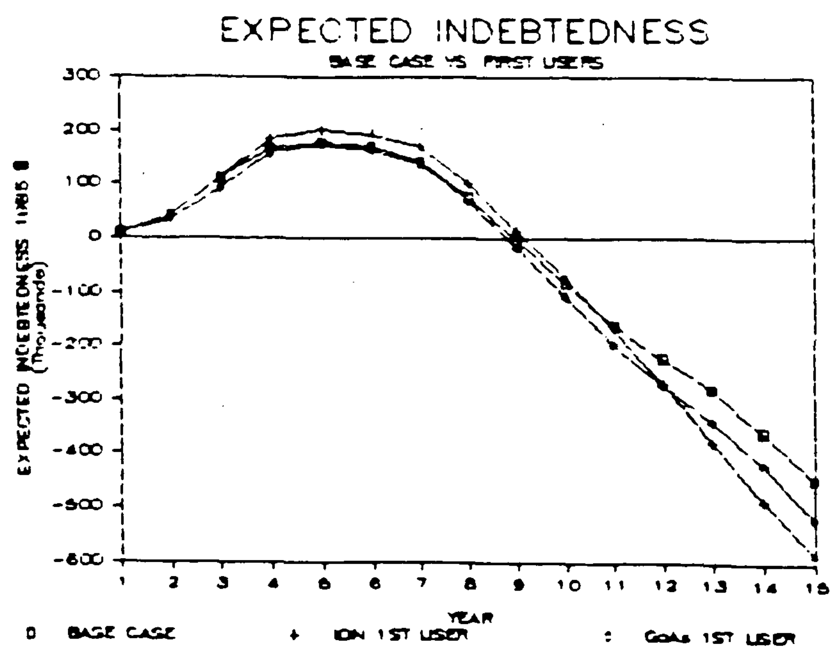

FIGURE 6.2 PSS EXPECTED INDEBTEDNESS - BASE CASE COMPARED WITH FIRST USER SCENARIOS

capabilities of the new technology satellites. Indebtedness is favorable over the entire fifteen year period for the GaAs scenario as compared to the base case. The ion-thruster scenario has accumulated slightly more debt by the fourth through the eighth years than the base case, but achieves a rapidly decreasing indebtedness from the ninth through the fifteen years. Tables 6.4 and 6.5, and corresponding graphs in Figures 6.3 and 6.4, compare profit and indebtedness data for the later users of the technology with the base case.

Because the nonrecurring costs have been reduced substantially as a result of the technology "maturing" and industry gaining experience building the improved technology satellites (hardware has been purchased, etc.), the improved technology scenarios are not disadvantageous in the early years, as is the case with the first users. Later the positive effects of the extended capability become apparent and the improved technology scenarios are significantly more attractive than the base case.

Occasional dips in expected profits, such as occurs in year thirteen with the base case and GaAs scenarios, is the result of additional satellite replacement launches.

Net present value for the infinite horizon at five different discount rates is displayed in Table 6.6 for the base case and improved technology scenarios. Figures 6.5 and 6.6 show net present value risk profiles for the scenarios at the 15% discount rate. At a 15% discount rate, if NASA undertakes the improved technology programs, expected net present value to the first users of both the ion-thruster and GaAs technologies will be

TABLE 6.4 PSS EXPECTED PROFIT - BASE CASE COMPARED WITH LATER USER SCENARIOS (THOUSAND OF 1985 $)

YEAR	EXPECTED PROFIT BASE CASE	EXPECTED PROFIT ION-THRUSTER	EXPECTED PROFIT GALLIUM ARSENIDE
1	(12324)	(12326)	(12329)
2	(5064)	(5063)	(5065)
3	(4686)	(4108)	(3624)
4	(2526)	(1431)	(854)
5	24439	28594	27421
6	30766	31383	32561
7	38021	38543	40207
8	60060	66242	66301
9	64320	71791	71937
10	66072	72738	73382
11	68870	79072	78419
12	63728	84081	74945
13	60122	90902	71345
14	70289	95991	82065
15	70694	87816	83415

( ) INDICATES A LOSS

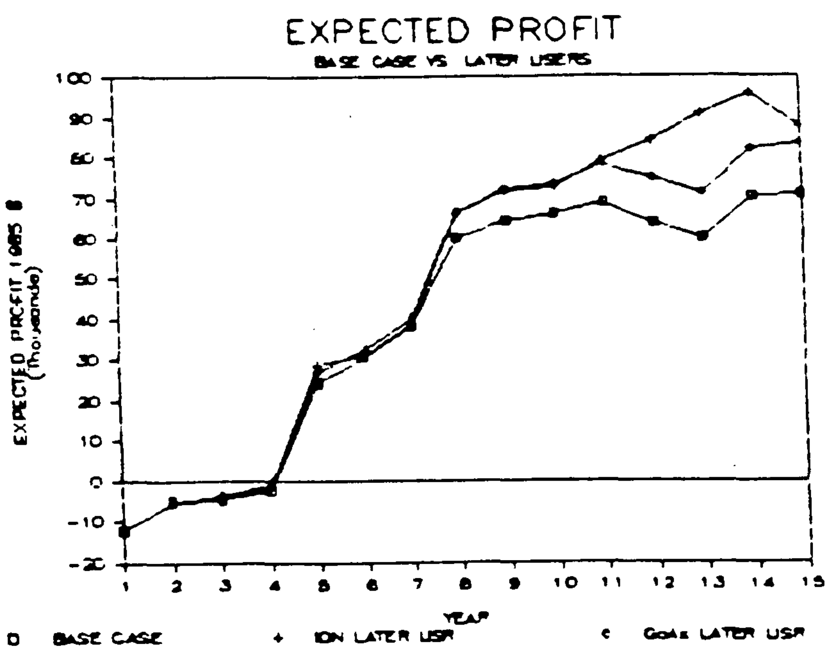

FIGURE 6.3 PSS EXPECTED PROFIT - BASE CASE COMPARED WITH LATER USER SCENARIOS

TABLE 6.5 PSS EXPECTED INDEBTEDNESS
BASE CASE COMPARED WITH LATER USER SCENARIOS
(THOUSANDS OF 1985 $)

YEAR	EXPECTED INDEBTEDNESS BASE CASE	EXPECTED INDEBTEDNESS ION-THRUSTER	EXPECTED INDEBTEDNESS GaAs SOLAR CELLS
1	11014	11016	11019
2	42642	35121	28817
3	110872	98496	84363
4	168545	169462	152601
5	179411	184186	166990
6	170589	174916	156471
7	142323	150760	130903
8	77454	80556	60743
9	(1789)	(8310)	(27294)
10	(83143)	(100138)	(118387)
11	(160122)	(196933)	(208765)
12	(221992)	(299792)	(285542)
13	(280519)	(409282)	(352656)
14	(358298)	(521243)	(436815)
15	(446913)	(625448)	(535710)

( ) INDICATES NEGATIVE INDEBTEDNESS

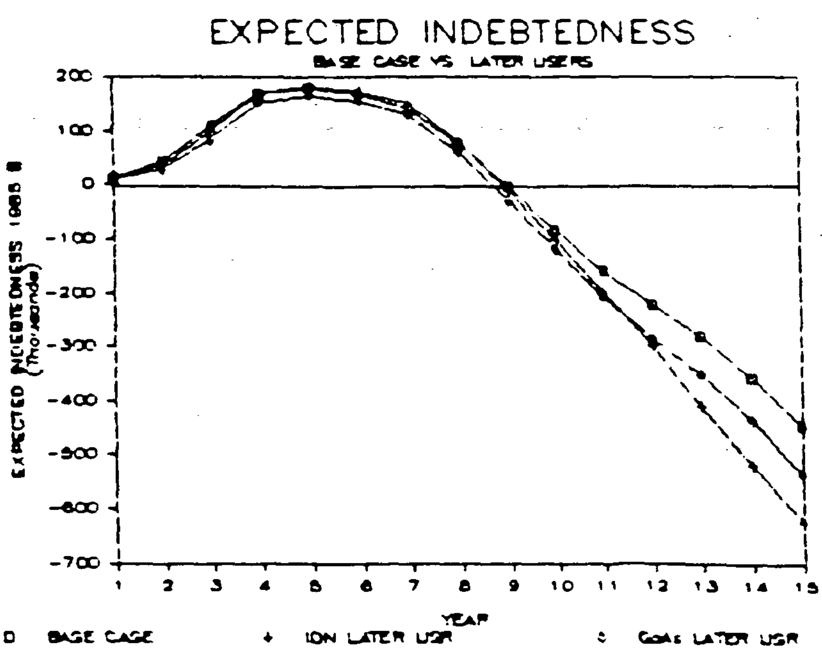

FIGURE 6.4 PSS EXPECTED INDEBTEDNESS - BASE CASE COMPARED WITH LATER USER SCENARIOS

TABLE 6.6 NET PRESENT VALUE* (MILLIONS OF 1985 $) AT VARIOUS DISCOUNT RATES

	DISCOUNT RATES				
SCENARIO	10	15	20	25	40
BASE CASE	$279.4	$ 84.2	$10.2	$(22.1)	$(45.0)
ION-THRUSTER FIRST USER	341.6	109.0	19.7	(19.5)	(47.9)
ION-THRUSTER LATER USER	367.9	127.3	34.0	(7.8)	(40.3)
GaAs FIRST USER	326.7	109.4	26.2	(10.6)	(38.8)
GaAs LATER USER	338.9	118.1	33.1	(4.8)	(34.7)

( ) INDICATES A NEGATIVE PRESENT VALUE
* INFINITE HORIZON

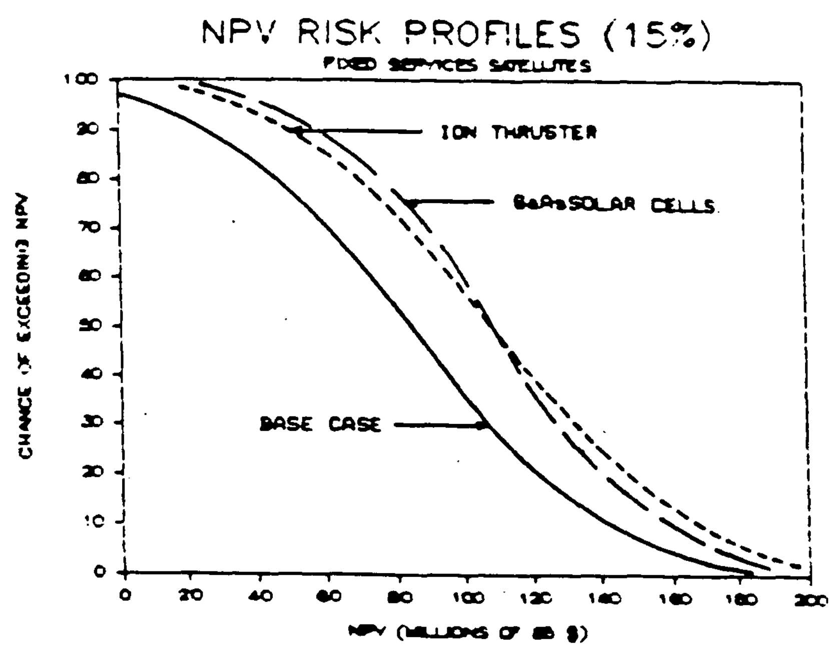

FIGURE 6.5 NET PRESENT VALUE AT 15% DISCOUNT RATE BASE CASE VS FIRST USER SCENARIOS

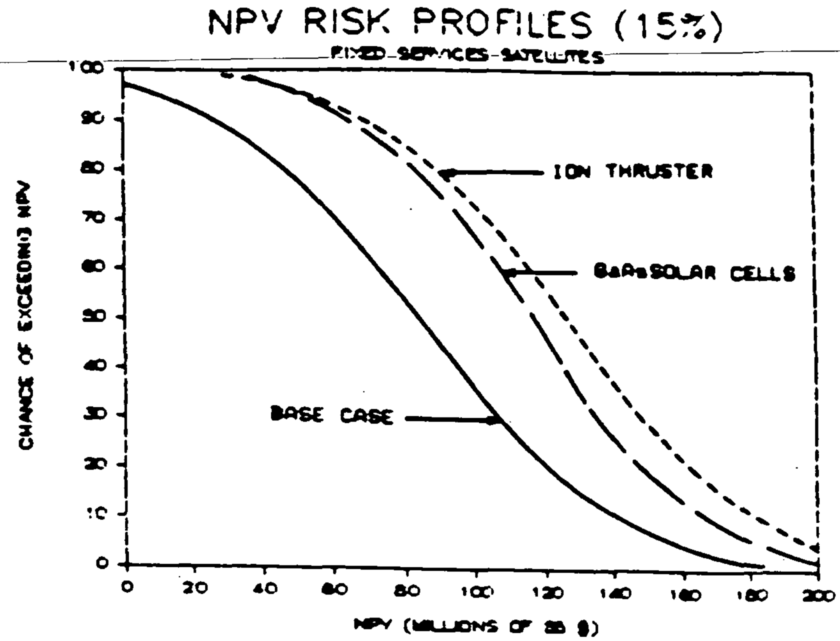

FIGURE 6.6 NET PRESENT VALUE AT A 15% DISCOUNT RATE
BASE CASE VS LATER USER SCENARIOS

approximately $25 million more than the base case. Once nonrecurring cost have been reduced to the base case level, the ion-thruster technology will generate an additional $18 million in net present value, and the Gallium Arsenide technology an additional $9 million.

Table 6.7 displays the expected return on investment (internal rate of return) and risk (the standard deviation of ROI) associated with each of the scenarios. The internal rate of return is the value of the discount rate that yields a present value of zero. If the internal rate of return is greater than the cost of capital it is desirable to pursue the venture.

Comparison of the expected ROI and the risk of the improved technology scenarios with the base case scenario leads to an interesting observation. There are small differences between the

TABLE 6.7 EXPECTED ROI AND RISK: BASE CASE COMPARED WITH NEW TECHNOLOGY SCENARIOS

	BASE CASE	ION-THRUSTER FIRST USER	GaAs FIRST USER
EXPECTED ROI	21.3%	22.1%	23.2%
RISK	2.9%	2.5%	2.4%
	BASE CASE	ION-THRUSTER MIDPOINT USER	GaAs MIDPOINT USER
EXPECTED ROI	21.3%	22.9%	23.6%
RISK	2.9%	2.5%	2.4%
	BASE CASE	ION-THRUSTER LATER USER	GaAs LATER USER
EXPECTED ROI	21.3%	23.7%	24.0%
RISK	2.9%	2.5%	2.4%

financial performance measures of the base case and the first user of the ion-thruster. These differences may be inadequate to gain early acceptance of the new technology by the private sector for commercial applications especially in light of the following.

Reliability (mean-time-to-failure) of the ion-thruster in the above described scenarios was assumed to be the same as the base case. Inadequate reliability data is available on ion-thruster technology to have confidence in the reliability

estimates utilized in the analysis. Reliability of this new technology could actually be lower than the base case reliability. Even if actual reliability is not lower, reliability could be perceived as low in the early use of the technology. In order to assess the impact of reliability, an analysis was performed which used an Attitude, Velocity and Control System (AVCS) mean-time-to-failure of 75 years (associated with a reliability of .899). The resulting expected ROI was 21.7 percent and the risk was 2.7 percent.

The first user may be discouraged by the fact that the technology is as yet unproven and risk could be perceived as high. This would most likely negate any slight advantage in expected ROI and risk that the ion-thruster scenario has over the base case. Furthermore because of the higher perceived risk, insurance rates are likely to be higher or insurance may not be available at all; this also would impact the financial results. (with the current high insurance rates and capacity limits it is important to consider technology programs and the insurance rate implications.)

The results indicate that there may be difficulty in motivating use of the technology because of increased nonrecurring cost and lack of sufficient reliability data. Once the technology has been applied, nonrecurring costs can be brought down and the difference in the expected ROI and risk for the later users may then be sufficient to induce later users to turn to this technology rather than continue with the base case technology. The results indicate that there would be difficulty

in motivating use of the technology if nonrecurring costs are not reduced and reliability demonstrated.

Nonrecurring costs of the first user were developed for an ion-thruster spacecraft for which only a feasibility demonstration was performed by NASA. The first user was assumed to bear the costs of qualifying the spacecraft and setting a standard modular design. If NASA chooses to encourage the technology then, based on the preceding analysis two steps may be taken. NASA may qualify the spacecraft. This would reduce the number of test articles that the contractor has to build. NASA could reduce costs further by producing a standard modular design. NASA may overcome industry reluctance to use ion-thruster technology by going beyond the research and development program to actually design and test a first prototype of the ion-thruster satellite. If NASA can in this way reduce the nonrecurring costs and demonstrate reliability (so as to reduce perceived risk), then the likelihood of the private sector utilizing the technology may be increased significantly. Otherwise, judging from the particular business scenarios considered in this study, it does not appear likely that the technology will be quickly adopted by the private sector.

Gallium Arsenide solar cell technology looks more promising. Both the expected ROI and the risk are clearly better than the base case scenario, even for the first user.

A number of plausible scenarios may be considered regarding the development of the improved technology, by the U.S. or the Europeans.

- o The U.S. does not fund research and development into the new technology but the Europeans continue R&D but don't bring down nonrecurring costs and risk.

- o The U.S. does not fund research and development of the new technology, and the Europeans continue R&D and significantly reduce nonrecurring costs and risk.

- o Both the U.S. and Europe develop the technology, but neither significantly reduce the risk and nonrecurring costs.

- o Both the U.S. and Europeans develop the technology but only the Europeans significantly reduce the risk and nonrecurring costs.

- o Both the U.S. and Europeans develop the technology and only the U.S. significantly reduces the nonrecurring costs and decreases risk.

- o Both the U.S. and Europeans develop the technology and both significantly reduce risk and nonrecurring costs.

Each of these scenarios has different implications for private sector adoption of the technology and the U.S. foreign trade picture. The second and fourth scenarios could result in the U.S. risking a portion of its potential market for satellites. This is discussed further in Section 7.2. The sixth scenario could mean that the technology is adapted and that the U.S. and Europe are on an equal footing competitively or that the U.S. is at an advantage.

6.3 Direct Broadcast Services Scenarios

A direct broadcast satellite business venture was hypothesized. The DBS satellite configured for the venture was based on the GE three-axis stabilized, high power (200 watt) satellite as described in Section 5. The business venture is based upon a two satellite system, launched on the Space Shuttle, with each satellite to serve one half the continental United States (CONUS). The second satellite is planned for launch six

months after the first. One type of service is to be offered. The transponders are in two groups. One group has a 4/2 redundancy configuration in which two spares back up two active transponders. The other has a 2/1 redundancy with 1 active transponder backed up by 1 spare.

A competitive market was envisioned for the high power DBS satellite because of the probability that low power fixed services satellites will be used to provide DBS service initially. Therefore price elasticity was assumed to be higher than unit elasticity (1.4). Lower prices were set in the first four years of satellite operation with the rationale that competition from lower powered systems would initially keep the price down. In later years prices rise as the market discovers that higher powered systems are better suited for DBS.

The analysis proceeded in the same manner as with the fixed services satellite scenarios, where reliability, cost, market and financial data make up a data base (see Appendix C) describing the postulated business scenario. Financial statements were generated for the base case scenario. The spacecraft was then reconfigured, once utilizing the ion-thruster technology and once utilizing the Gallium Arsenide solar cell technology.

When reconfigured utilizing the ion-thruster technology the satellite mass is reduced by approximately 28 kilograms. If the margin is reduced by another 22 kilograms, one additional transponder and two additional years of on-orbit propulsion system life can be designed into the satellite without increasing the mass beyond the base case liftoff mass. The satellite when reconfigured utilizing the Gallium Arsenide solar cells can

achieve a mass reduction of 13 kilograms. If another 15 kilograms is taken from the margin, two additional years of on-orbit propulsion system life may be achieved while maintaining the same liftoff mass as the base case satellite.

The data bases were adjusted with appropriate parameters describing the two "extended capability" satellites and the financial statements representing the new improved technology scenarios were generated. The parameters that are changed to describe the new scenarios are, the number of transponders and additional years of life, nonrecurring and recurring costs. These parameters are displayed in Table 6.8. All other parameters were held constant with the base case scenario. Analyses were performed with two different nonrecurring costs to

TABLE 6.8 PARAMETERS THAT VARY WITH SCENARIO DIRECT BROADCAST SATELLITE

	BASE CASE	ION-THRUSTER	GALLIUM ARSENIDE
NONRECURRING COST*			
MINIMUM	$19.8	$ 72.0	$43.0
EXPECTED VALUE	20.8	75.8	45.3
MAXIMUM	25.0	113.7	67.9
RECURRING COST*			
MINIMUM	36.4	71.8	61.1
EXPECTED VALUE	38.6	77.2	65.7
MAXIMUM	40.9	82.6	70.2
NUMBER OF ACTIVE	3	4	3
LIFE (AVCS) TRANSPONDERS	7 YEARS	9 YEARS	9 YEARS

* MILLIONS OF 1985 DOLLARS

represent a first user, and a later user.

6.4 Direct Broadcast Satellite - Results

Use of the ion-thruster technology satellites by the typical DBS venture results in a reduction of expected profit and an increase in indebtedness (compared to the base case) in the near-term. In the long-term, profit is increased and indebtedness is decreased. The effects of the use of Gallium Arsenide solar cell technology are not as marked: in the near-term the impacts are slightly negative or insignificant while in the long-term the effects are distinctly better than the base case but not a good as the ion-thruster scenario.

The particular DBS business scenario and S/C configuration selected for the analysis is not likely to be financially viable, judging from the financial statements generated by the base case analysis. This should not be generalized since these results reflect only the particular scenario and configuration chosen and do not mean that other DBS business scenarios would be unattractive. It was hoped that application of the improved technologies might turn a marginally unattractive business venture into an attractive one. Unfortunately, this does not appear to be the case for the specific technologies and business scenario considered.

In the early years of the venture the improved technology first user scenarios incur larger losses and higher indebtedness (especially the ion-thruster scenario) than the base case because of the higher nonrecurring costs. From the seventh year on the difference in capability of the improved technology satellites

become apparent as expected profit of the improved technology scenarios begins and continues to exceed the base case expected profit. In the eleventh and twelfth years the base case profit dips significantly due to satellite replacement launches, while the improved technology scenarios (with enhanced capability satellites) maintain profit levels. Expected profit is displayed in Tables 6.9 and 6.10 and illustrated in Figures 6.7 and 6.8.

Indebtedness in the base case is positive during the entire fifteen period; the payback period in the base case therefore exceeds fifteen years. The improved technology scenarios have payback periods of thirteen and fourteen years for the first user scenarios and twelve and thirteen years for the later user scenarios. The magnitude of indebtedness is greater (and often subtantially greater) under the ion-thruster scenarios than the base case until the eleventh (first user) or tenth (later user) years. A comparison of expected indebtedness for each of the scenarios is presented in Tables 6.11 and 6.12 and Figures 6.9 and 6.10.

Net present value is negative at all five discount rates for all scenarios. For an attractive investment, net present value should exceed zero at the firm's cost of capital (discount rate). By this criterion none of the proposed scenarios are financially attractive investments. The application of the improved technologies and use of the resulting expanded capacity satellites have not succeeded in making this hypothetical business into a financially attractive business. This may not be the case for other DBS business scenarios.

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TABLE 6.9 DBS EXPECTED PROFIT
BASE CASE VS FIRST USER SCENARIOS
(THOUSANDS OF 1985 $)

YEAR	BASE CASE	ION-THRUSTER	GaAs
1	(22525)	(17572)	(19025)
2	(9498)	(27633)	(16894)
3	(7726)	(19255)	(7946)
4	(5341)	(8290)	(5478)
5	18457	18649	18190
6	14455	9423	14639
7	14441	21475	15242
8	22243	25162	22804
9	24377	27973	25298
10	25867	30134	27604
11	16722	33887	30118
12	6709	35782	32111
13	12820	28183	23699
14	22762	24373	21574
15	30826	28543	25992

( ) INDICATES A LOSS

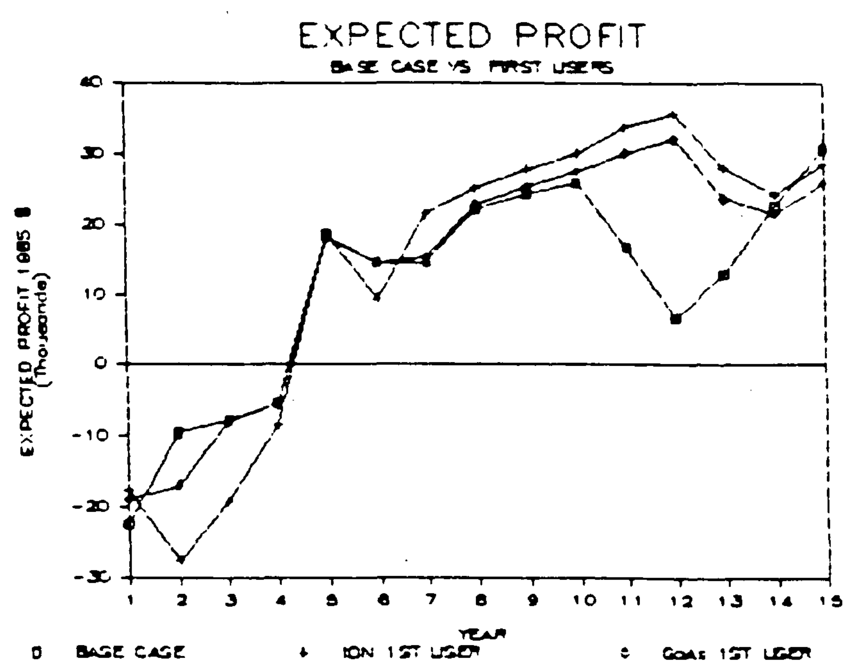

FIGURE 6.7 DBS EXPECTED PROFIT - BASE CASE VS FIRST USER SCENARIOS

TABLE 6.10 DBS EXPECTED PROFIT
BASE CASE VS LATER USER SCENARIOS
(THOUSANDS OF 1985 $)

YEAR	BASE CASE	ION-THRUSTER	GaAs
1	(22525)	(22359)	(22471)
2	(9498)	(9443)	(9480)
3	(7726)	(7955)	(7701)
4	(5341)	(6485)	(5156)
5	18457	20670	18535
6	14455	11597	15011
7	14441	23816	15642
8	22243	27681	23234
9	24377	30684	25761
10	25867	33051	28103
11	16722	37026	30655
12	6709	39161	32689
13	12820	31819	24321
14	22762	28286	22243
15	30826	32755	26713

(   ) INDICATES A LOSS

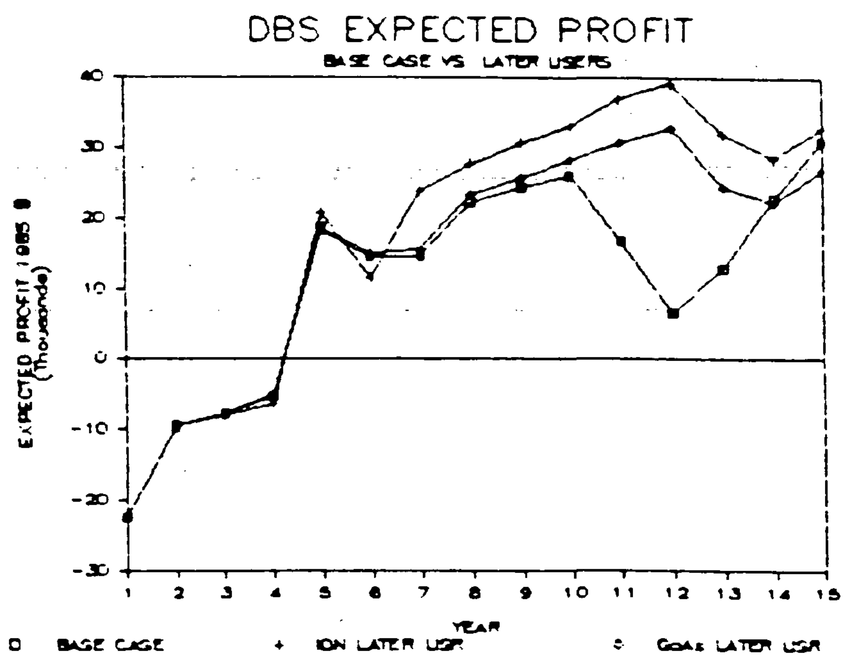

FIGURE 6.8 DBS EXPECTED PROFIT - BASE CASE VS LATER USER SCENARIOS

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TABLE 6.11 DBS EXPECTED INDEBTEDNESS
BASE CASE VS FIRST USER SCENARIOS
(THOUSANDS OF 1985 $)

YEAR	BASE CASE	ION-THRUSTER FIRST USER	GaAs FIRST USER
1	20132	15705	17004
2	64616	79058	67475
3	159866	196805	162626
4	251318	303392	252101
5	269882	326944	268562
6	247561	306429	245031
7	218889	270934	215665
8	183832	228701	180261
9	146609	183356	140836
10	120068	135297	98965
11	117398	85330	56005
12	122603	44649	20831
13	103729	18069	(1273)
14	63203	(9449)	(25335)
15	15931	(46232)	(59387)

( ) INDICATES NEGATIVE INDEBTEDNESS

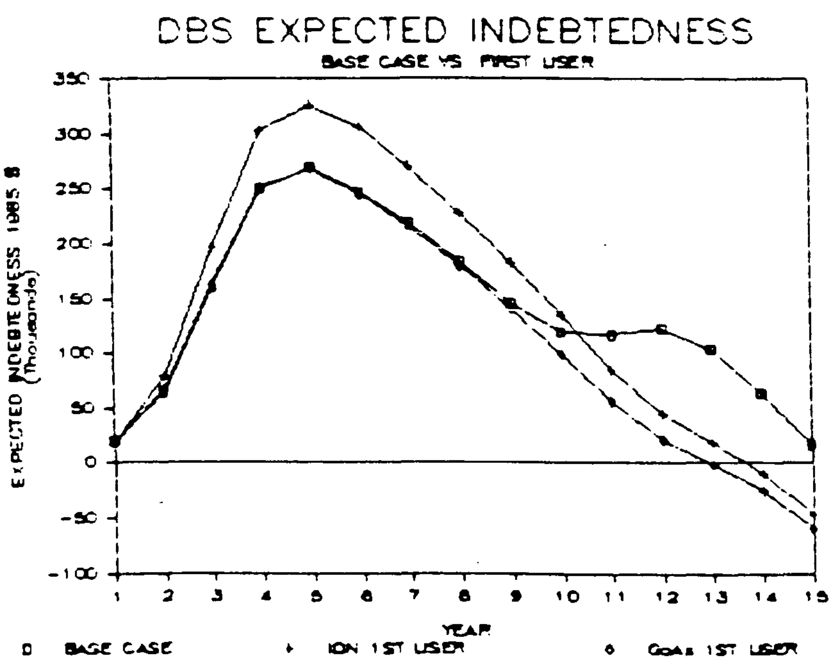

FIGURE 6.9 DBS EXPECTED INDEBTEDNESS - BASE CASE VS FIRST USER SCENARIOS

TABLE 6.12 DBS EXPECTED INDEBTEDNESS
BASE CASE VS LATER USER SCENARIOS
(THOUSANDS OF 1985 $)

YEAR	BASE CASE	ION-THRUSTER LATER USER	GaAs LATER USER
1	20132	19984	20083
2	64616	67588	64294
3	159866	173302	158439
4	251318	277075	247600
5	269882	298629	263719
6	247561	275956	239818
7	218889	238138	210055
8	183832	193406	174224
9	146609	145370	134338
10	120068	94416	91972
11	117398	41332	48479
12	122603	(2702)	12732
13	103729	(32891)	(9991)
14	63203	(64294)	(34717)
15	15931	(105257)	(69484)

( ) INDICATES NEGATIVE INDEBTEDNESS

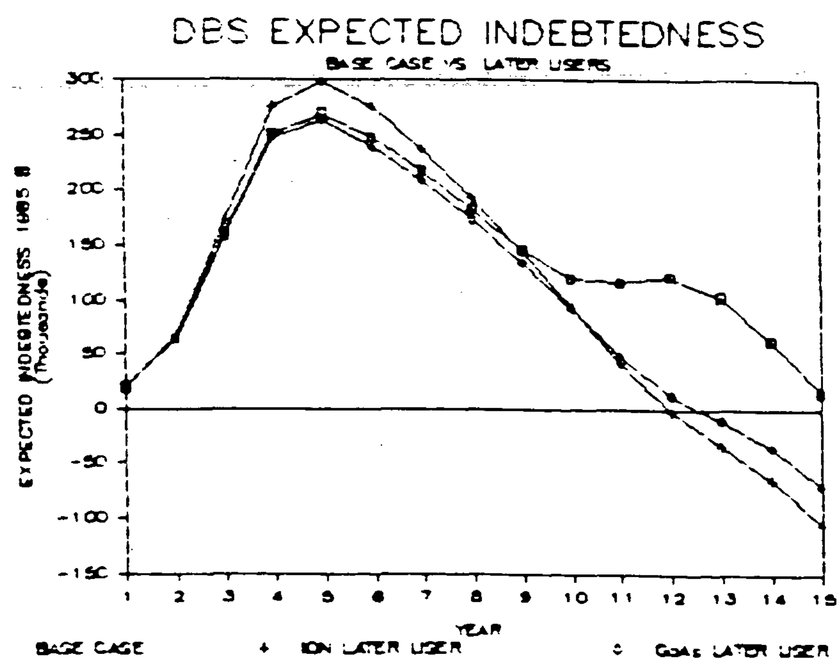

FIGURE 6.10 DBS EXPECTED INDEBTEDNESS - BASE CASE VS LATER USER SCENARIOS

TABLE 6.13 NET PRESENT VALUE* (MILLIONS OF 1985 $) AT VARIOUS DISCOUNT RATES

	DISCOUNT RATES				
SCENARIO	10	15	20	25	40
BASE CASE	$(104.2)	$(112.1)	$(111.5)	$(106.9)	$ (87.4)
ION-THRUSTER FIRST USER	(101.0)	(119.8)	(124.6)	(122.6)	(103.0)
ION-THRUSTER LATER USER	(68.6)	(94.0)	(103.5)	(104.8)	(91.4)
GaAs FIRST USER	(75.1)	(93.5)	(99.5)	(99.0)	(84.9)
GaAs LATER USER	(69.7)	(89.3)	(96.0)	(96.2)	(83.2)

( ) INDICATES A NEGATIVE NET PRESENT VALUE
* DISCOUNTED OVER YEARS ONE THROUGH FIFTEEN

6.5 Observations

Two technologies that could result from NASA technology programs have been evaluated in terms of their effect the on the financial performance of two typical communications satellite business ventures. The analysis considered a fixed services satellite business and a direct broadcast satellite business.

The FSS business is a reasonable business to begin with, one that earns an attractive return on investment when utilizing a satellite that does not employ the new technologies. Utilizing satellites employing the two new technologies had a positive

impact on the financial performance of this business, in general. In the near-term, large additional investments required of the firm as a result of higher nonrecurring costs of satellites employing the new technologies increase losses and indebtedness relative to the base case. In the long-term the effect of increased capacity resulting from incorporating the new technology into the satellites positively effect profits and reduces indebtedness relative to the base case. When the business is considered over the long-term, the return on investment when the business uses the new technologies is better than the base case. However, if the business is a first user of the ion-thruster technology, the financial measures may not be favorable enough to warrant the additional investment in the near-term to achieve the long-term rewards. Investment in new technology by a first user to achieve long-term enhanced financial performance is uncertain, because the improvement in long-term financial measures may not be sufficient if the first user has to bear the nonrecurring costs after only a feasibility demonstration phase by NASA. This may pose a hurdle that NASA could only overcome by performing research and development beyond the feasibility demonstration phase. NASA could reduce nonrecurring costs to the first user by qualifying the prototype satellite, producing a standard modular design and demonstrating reliability.

The particular direct broadcast satellite business venture selected for analysis was found to be unattractive as indicated by the financial performance measures generated by the base case

scenario. Although losses turn to profits within the fifteen period evaluated, the net present value of cash flow is negative at all of the considered discount rates, an indication that no prudent investor would invest in that particular business. It is hoped that the utilization of the new technology satellites with increased capabilities would significantly after this situation. Application of the new technologies caused improvements in profit and indebtedness over the long-term, but was not of sufficient benefit to transform the business into a viable one.

It must be emphasized that this analysis considered only two representative business scenarios, as defined in the preceding sections. Impacts of the new technology satellites may differ when considering other business scenarios.

7. SPACECRAFT MARKETS AND TECHNOLOGY IMPLICATIONS

7.1 Value of Technology Programs

Net present value (NPV), the discounted stream of future cash flows, is an accepted measure of project's worth to a business. The difference between the NPV of two projects provides a measure of the expected value of one investment relative to the other.

The analyses described in the previous pages resulted in the determination of the increase in the NPV that a typical venture is likely to experience as a result of utilizing improved technology satellites. The utilization of ion-thruster satellites is expected to increase NPV by $25 to $40 million (at a discount rate of 15%) relative to the base case. Utilization of GaAs technology could increase NPV by $25 to $35 million (at a discount rate of 15%).

These increments in NPV may be viewed as the benefits to a typical firm of investment in the improved technology satellites. As a first order approximation, these changes in NPV may be extrapolated to the industry by multiplying the likelihood of a business venture using the technology by the expected increase in NPV of the business venture and the expected number of business ventures that might utilize the improved technology satellites.

Estimating the number of businesses that could benefit from the improved technology satellites requires projections of supply and demand. Recently, several studies forecasting sharply increasing transponder demand concluded that demand for

TABLE 7.2 ESTIMATED DEMAND FOR 36MHz EQUIVALENT TRANSPONDERS

	1990	1994	1995	1996	1997	1998	1999	2000
TRANSPONDERS	1145	1655	1783	1911	2039	2168	2296	2424

transponders would exceed capacity in the 1990's. More recently several factors have tempered this optimism and some are anticipating a transponder glut through the early nineties. These factors include the potential competition of fiber optics, the large projected supply of transponders (based on current and approved capacity and satellite applications pending before the FCC), and possibly an already existent oversupply (based on the FCC's spot check of transponders in use [1]).

The number of businesses that will launch communications satellites may be estimated by (a) selecting demand forecast and a supply forecast based on capacity that will be available using current technology satellites and (b) determining the amount of transponder capacity that will have to be available to fill estimated excess demand that will emerge once the satellites start to fail.

A recent NASA study [2] estimates the demand for 36 MHz equivalent transponders for the years 1980, 1990 and 2000. Table 7.2 presents the demand forecast using the NASA estimates for 1990 and 2000 and interpolating linearly between the two points.

If all satellites that have been approved by, and are currently pending before the FCC are actually launched, and if these satellites and those currently on-orbit achieve their

TABLE 7.3 TOTAL PROJECTED SUPPLY OF U.S. COMMERCIAL SATELLITE TRANSPONDERS (EQUIVALENT 36 MHz) 1995-2000

	1995	1996	1997	1998	1999	2000
TRANSPONDERS	1873	1830	1463	768	536	381

expected lifetimes, then there will be more than sufficent capacity to fill the above demand forecast until 1995. Table 7.3 is a projection of transponder supply [1] based on current satellites on-orbit, satellites currently approved by the FCC and satellites that are still pending FCC approval under the current round of applications.

Using the demand and supply forecasts described above, a glut is foreseen through the mid-1990's. Around 1996 there will begin to be a gap between supply and demand, considering supply as defined above (and not including any satellites included in a subsequent round of FCC filings). The present, current pending and current approved capability will have started to fail, and

TABLE 7.4 SUPPLY AND DEMAND OF EQUIVALENT 36 MHZ TRANSPONDERS 1995-2000

	1995	1996	1997	1998	1999	2000
TRANSPONDER SUPPLY	1873	1830	1463	768	5367	381
TRANSPONDER DEMAND	1783	1911	2039	2168	2296	2424
EXCESS DEMAND	-90	81	576	1400	1760	2043

demand will continue to grow. At this point new satellites will be constructed and launched to fill the gap. The lead time for construction and launch and FCC approval require the decision to launch new satellites be made 4 or 5 years prior to launch.[1] Therefore choices regarding satellite configuration and technology will start to be made early in the nineties. The technology must be available by then in order to be available for inclusion into the next generation of satellites: those placed into orbit after the current* group starts failing.

If the technology is available as early as 1991 the following estimate may be made of the number of businesses that would be able to utilize the technology. Table 7.4 indicates the estimated transponder demand and supply for the years 1995 through 2000. The difference between demand and supply ranging from 81 transponders in 1996 to 2043 transponders in 2000, is illustrated in Figure 7.1. If there are 20 transponders per satellite, on average, about 100 satellites must be launched by 2000 to fill estimated demand.

Table 7.5 indicates the number of satellites per year that would have to be launched to satisfy the excess demand. If a typical business operates three to five satellites, then between twenty and thirty-four ventures may benefit from the new technology by placing satellites incorporating the new technology into orbit in the 1996 - 2000 time frame.

* Current includes those pending now before the FCC - it is assumed that design decisions have already been made on these and that the new technology will not be ready by the time most of this group is ready for launch.

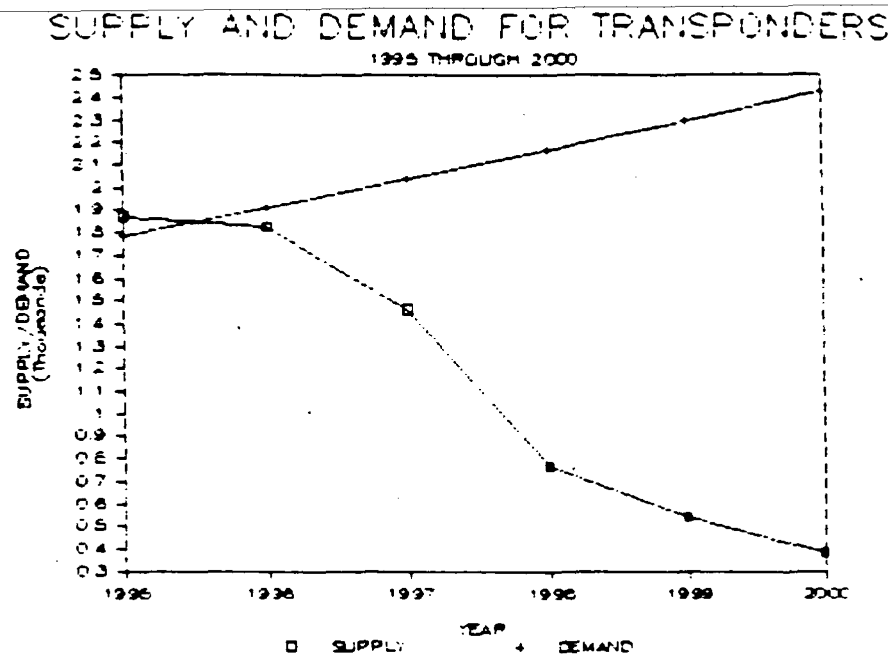

FIGURE 7.1 SUPPLY AND DEMAND FOR EQUIVALENT 36MHz TRANSPONDERS

The likelihood that a business will choose to invest in the new technology is a function of the financial benefits likely to result from the new technology and the cost of introducing the technology. For instance, the likelihood that a business will invest in the ion-thruster satellite as a first user, while nonrecurring costs are still high, is much lower than the likelihood of a business investing in the ion-thruster satellite as a later user, after nonrecurring costs have been reduced.

TABLE 7.5 NEW SATELLITES ON-ORBIT ANNUALLY TO FILL EXCESS DEMAND

	1996	1997	1998	1999	2000
NUMBER OF SATELLITES	4	25	41	18	14

As discussed in Section 6, if NASA only develops the technology to the point of a feasibility demonstration phase, a first user of the ion-thruster technology satellite may not find the financial performance measures to be attractive enough to invest in the technology. Nonrecurring costs are high, and the ROI is not significantly better than that of the base case. Risk may be perceived as higher than the base case because the technology is as yet unproven.*

NASA may increase the likelihood of an initial investment in ion-thruster technology by taking the research beyond the feasibility demonstration phase. By qualifying the spacecraft and producing a standard modular design, NASA can reduce nonrecurring costs to the first user. Furthermore NASA might influence perceived risk by reliability demonstrations. This would reduce cost further because the satellite has been designed with two propulsion systems - an ion propulsion system and a chemical backup system: once the technology is proven the two systems may not be necessary. Performance of this second phase of research and development could then increase the chance of the increased net present value being realized by a number of businesses because the likelihood of there being an initial investment may be increased.

To illustrate, suppose that NASA only performs a feasibility demonstration (phase 1). A first user may not find sufficient

* Although a chemical propulsion system is designed into the satellite as backup, it does not provide the same reliability as the base case satellite since it does not have enough propellant to carry the satellite for the entire design life.

financial motivation to invest in the technology, and the technology may literally never get off the ground. If this is the case the net present value increases will not be attained by later users. The probability of there being a first user, and therefore subsequent users is low.

If nonrecurring costs are reduced, there is a greater likelihood that there will be a first user of the technology. Consequently, there is also a greater likelihood that subsequent businesses will also utilize the technology thereby achieving increased NPV. If NASA undertakes a demonstration program (phase 2) aimed at reducing nonrecurring costs, the chances are greater that these benefits will be realized.

Estimation of the effect of Phase 2 on NPV (extrapolated to the industry) may be illustrated using the following simplified model. Suppose that there are only first users and later users. A first user represents the user who would bear the initial nonrecurring costs if there were no Phase 2. Later users represent either those investing after the first users or represent all users if NASA undertakes Phase 2.

If $P1$ = probability of private sector investment in technology if only Phase 1

$\Delta PV1$ = the change in present value to the first user of the technology (relative to the base case)

$\Delta PV2$ = the change in present value to the later users (relative to the base case)

N = number of potential users

$P2$ = probability of private sector investment in technology if Phase 1 and 2 programs are undertaken by NASA.

The value of performing Phase 1 is:

$$P1 * (\Delta PV1 + (N - 1) * \Delta PV2)$$

The benefit of performing both Phases 1 and 2 is:

$$P2 * (N * \Delta PV2)$$

and the benefit of performing Phase 2 alone is:

$$(P2 - P1) * N * \Delta PV2 + P1 * (\Delta PV2 - \Delta PV1)$$

The value of P2 should be significantly greater than P1: the likelihood of private sector investment in the technology is increased by the government undertaking the second phase of the research and development.

Assigning values to the variables based on results from the analysis and guessing values for P1 and P2 as follows:

$$\begin{aligned} P1 &= .1 \\ P2 &= .8 \\ N &= 30 \\ \Delta PV1 &= \$25 \text{ million} \\ \Delta PV2 &= \$43 \text{ million} \end{aligned}$$

the value of Phase 1 would be $130 million, the value of Phases 1 and would be $1030 million, and the value of Phase 1 alone would be $900 million. It should be noted that the benefits depend heavily upon P2 - P1. Thus over wide ranges of P2 and P1 significant benefits may be achieved by performing Phase 2.

7.2 Potential Impact on Imports and Exports

Most of the commercial communications satellites in orbit have been supplied by U.S. companies. [3] Foreign countries have recently been developing the capability to manufacture communication satellites and U.S. manufacturers can expect to face increasing competition from abroad. The Europeans have advanced in the design and development of three-axis stabilized spacecraft for communications satellites. The development of the European regional communications satellite system, Eutelsat, was

sponsored by the European Space Agency and the satellites were built by a British multinational group with French, German and Italian participation. Japan has already orbited a series of communications satellites and is developing a new high capacity satellite. [4]

The Europeans and Japanese have been developing Silicon and Gallium Arsenide solar cells and intensive programs to develop ion propulsion are underway in France and Germany. Even if the U.S. does not develop improved technology in these two areas it appears that the technology will be available from foreign sources.

The previous sections describe the effects of ion-thruster and Gallium Arsenide technology on communications satellite business ventures using two particular spacecraft configurations: the FSS venture was based on a Hughes spin stabilized Ku-band satellite, and the DBS venture was based on a GE three-axis stabilized satellite. The results presented indicate that there are likely to be benefits to fixed communications satellite business ventures from using ion propulsion and Gallium Arsenide solar cells. In the case of ion-thruster technology these benefits may only come about if NASA goes beyond the feasibility demonstration phase to qualify the spacecraft, produce a standard modular design and demonstrate reliability. With Gallium Arsenide technology, the analysis showed that, based on the particular business scenario analysed, improved financial performance measures would result from application of the technology by the first user of the technology after only a

feasibility demonstration program by NASA. The specific benefits will depend upon the particular business venture utilizing the new technologies and the specific satellite configurations employed.

Improved technology (both ion-thruster and Gallium Arsenide), on the other hand, did not have favorable enough effects on the particular DBS venture that was analysed. This particular venture was an unattractive one to begin with (it must be stressed here that this is not to say that other DBS businesses may be financially untenable , but it is rather because of the specific configuration that was used in the analysis - a satellite with only three active transponders). Use of the new technologies did not make the business a viable one. The results therefore suggest that the specified ion-thruster and Gallium Arsenide technology may not be profitably applied to the higher power DBS satellites (since business ventures using the considered satellite configuration may not be viable in their own right).

Extrapolation from the limited developed data points to the broad range of <u>fixed</u> communications satellite business ventures leads to the conclusion that improved technology satellites (i.e., incorporating ion propulsion and/or Gallium Arsenide solar cells) would potentially have a competitive advantage on the world market because of the positive effects such satellite cound have on the financial performance of the businesses owning the satellites. (As discussed above, this competitive advantage would be more likely to result for ion-thruster technology if nonrecurring costs could be brought down and high reliability

demonstrated.) If the U.S. does not develop ion propulsion technology and improved solar cells whereas the Europeans or Japanese do, U.S. manufacturers may lose a portion of the world satellite market to the competition.

Estimation of the size of the potential market "at risk" or the market that the U.S. could lose if foreign technology advances faster than U.S. technology may be approached as follows. A study by Communications 21 [4] estimated planned worldwide investment in commercial communications satellites. Figure 7.2 illustrates the expected investment by area during the years 1990 and 2000, according to the study. The study listed past, present and expected future communications satellites worldwide and indicated cost, country of owner and contractor for the satellite (when available). Table 7.6 is an example of information presented in the study. Estimates resulting from this study may be high and may overestimate the actual market since many satellites listed after 1985 are not yet under contract and it is not certain the satellites will be launched.

Because the reported financial analysis indicated that the considered new technologies may not sufficiently alter the financial performance of the considered DBS businesses, the market for DBS satellites was not considered part of the market at risk.

Satellite purchases for which the satellite contractor was already determined (for instance Intelsat will purchase three satellites from Hughes for launch in 1992), were not considered

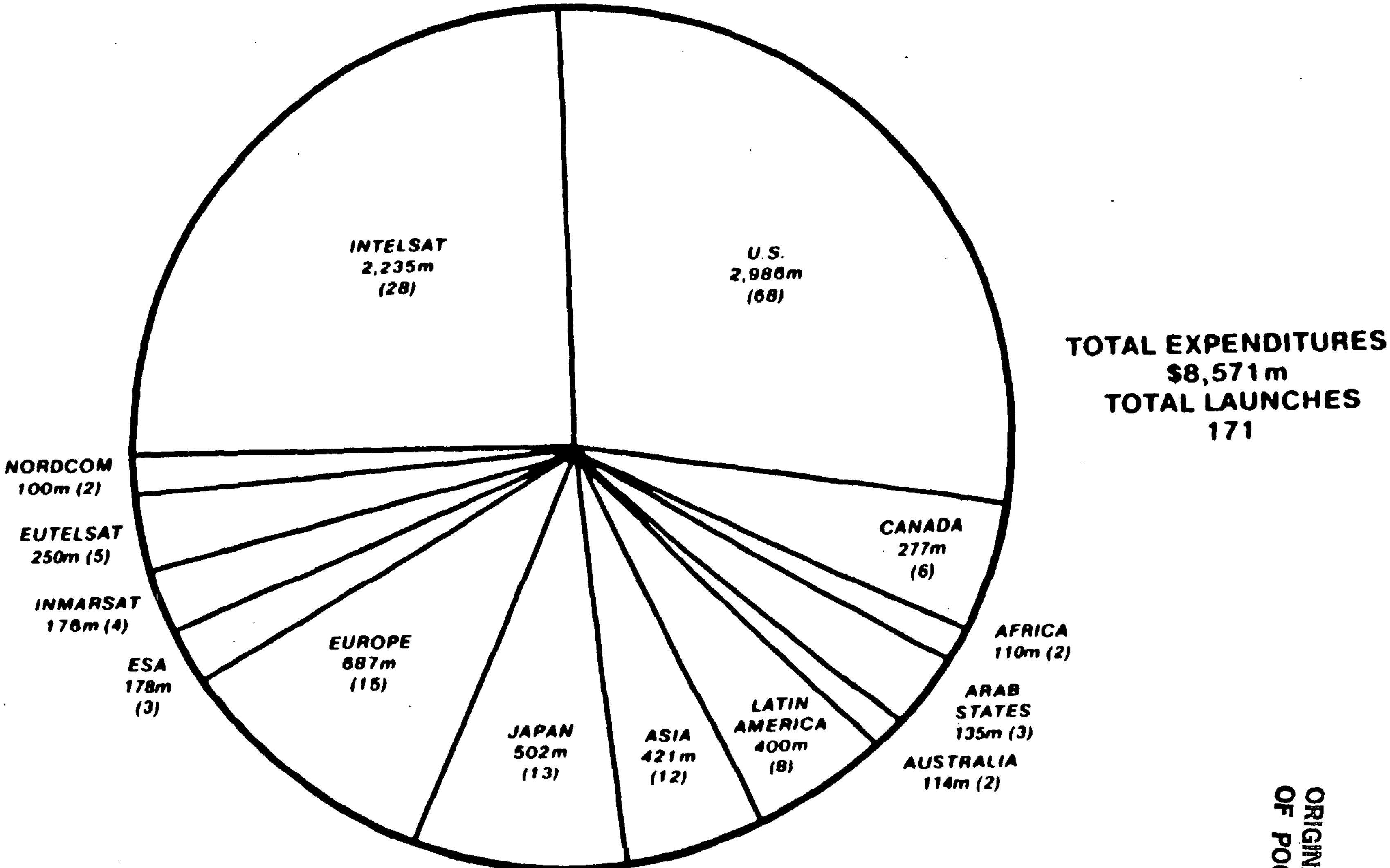

FIGURE 7.2 PLANNED WORLDWIDE INVESTMENT IN COMMERCIAL COMMUNICATION SATELLITES 1900 - 2000

SOURCE: FILEP, R., SCHNAPF A., AND FORDYCE, S., WORLD COMMUNICATIONS SATELLITE MARKET CHARACTERISTICS AND FORECAST, COMMUNICATION 21 CORP., NOV. 1983

TABLE 7.6 PAST PRESENT AND FUTURE COMMERCIAL SATELLITES

"COUNTRY"	LAUNCH YEAR	CONTRACT YEAR	COST PER SATELLITE (M$)	SATELLITE	ACTUAL TRANS-PONDERS	E.T.	FREQUENCY BAND	DESIGN LIFETIME (YEARS)	PRIME CONTRACTOR	P
GERMANY	1986	1984	55	TV-SAT DS	5	n/a	Ku(BSS)	7	Eurosatellite	
CUBA	1988	1985	50	CUB-A	24	24	C	10		.5
KOREA	1988	1985	35	KOR-2	3	n/a	Ku(BSS)	7		
JAPAN	1988	1984	65	CS-3A	8	54	Ka/C		Melco	
	1988	1984	65	CS-3B	8	54	Ka/C		Melco	
U.S.	1989	1985	80	CBS-D	3	n/a	Ku(BSS)	10		.7
	1989	1985	80	CBS-E	3	n/a	Ku(BSS)	10		.7
	1989	1985	75	US DBS	6	n/a	Ku(BSS)	7		.5
	1989	1985	75	US DBS	3	n/a	Ku(BSS)	7		.5
	1989	1984	45	ISI-1	24	24	Ku	10		.7
	1989	1985	36	SBS-B	24	24	Ku	10	Hughes	
	1989	1985	45	US DOMSAT	24	24	C/Ku	10		
	1989	1985	45	US DOMSAT	24	24	C/Ku	10		
	1989	1985	45	US DOMSAT	24	24	C/Ku	10		
	1989	1985	50	US DOMSAT	24	24	C/Ku	10		
	1989	1984	58	US DBS	6	n/a	Ku(BSS)	7		
	1989	1984	60	DBSC-DBS-C	6	n/a	Ku(BSS)	7		.7
	1989	1984	58	US DBS	6	n/a	Ku(BSS)	7		
JAPAN	1989	1985	41	BS-3B	3	n/a	Ku		Melco	.7
SWITZERLAND	1989	1985	40	HELVESAT	4/4/4	36	C/Ku/Ka	10		.7
	1989	1985	40	HELVESAT	4/4/4	36	C/Ku/Ka	10		
INTELSAT	1989	1984	67	I-VI F13	36/10	46	C/Ku		Hughes	
	1990	1984	67	I-VI F14	36/10	46	C/Ku		Hughes	
	1990	1984	67	I-VI F15	36/10	46	C/Ku		Hughes	
	1990	1984	67	I-VI F16	36/10	46	C/Ku		Hughes	
U. S.	1990	1984	44	ORION	20	20	C	10		.7
	1990	1987	45	TELSTAR-R	24	24	C/Ku	10		
	1990	1987	50	RCA-DBS-D	3	n/a	Ku(BSS)	10	RCA	.7
IRELAND	1990	1985	60	ERINSAT-A	12/4	36	Ku/Ku/BSS			.7
E. S. A.	1990	1987	59	L-SAT (OLYMPUS-2)	3	n/a	Ku(BSS)	10		
PAKISTAN	1990	1986	35	PAKSAT	12	36	C/Ku	10		

SOURCE: FILEP, R., SCHNAPF A., AND FORDYCE, S., WORLD COMMUNICATIONS SATELLITE MARKET CHARACTERISTICS AND FORECAST, COMMUNICATION 21 CORPORATION, NOVEMBER 1983

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part of the market the U.S. risks losing if the technology is not developed by the U.S.

For many of the potential satellite purchases listed in Reference 4 the contractor has not yet been determined, however. Some of these potential markets would not be open to U.S. manufacturers in any case because of nationalistic policies. In Western Europe, communications systems are operated by the government postal-telephone-telegraph agencies which are committed to buying nationally and American manufacturers are therefore barred from the European market. [3] Since Europe is likely to supply itself, Europe, including ESA and Eutelsat, is not considered part of the market at risk.

Until recently Japanese policy, based on the country's Space Development Principle, has been to protect its national space industry and build up an advanced and competitive commercial space industry with Japanese technology. In fact, the government has allowed development and launch of Japanese spacecraft even if more costly than U.S. spacecraft. [5] The Japanese government has recently reversed this policy to accelerate purchase of U.S. manufactured communications satellites. [6] In fact, joint ventures are being formed in Japan to market American made communications satellites. Space Communication Corporation, for example, (a joint venture between Mitsubishi Trading Corporation and Mitusbishi Electric Corporation) plans to market Ford Aerospace satellites. [7] Other events may further open Japanese doors to U.S. communications satellites. Nippon Telegraph and Telephone has just been denationalized. [8] Of even greater import, Japan just decided to release a portion of the Ku-band

for domestic communications satellite operations in Japan. [7] Until this decision there was little optimism concerning potential U.S. inroads into the Japanese market because communication satellites in Japan have been allocated Ka-band frequencies (a small amount of Ku-band has been used for communications with foreign satellites). The U.S. would not have been able to supply cost-competitive Ka-band satellites. [8]

Because of these developments it appears that the U.S. may have more success than before in penetrating the Japanese market. It could be assumed that the U.S. might capture 25% of the Japanese market, if the relative technology levels were to remain the same. If Japan is successful in developing advanced technology the U.S. could lose this part of the market. Therefore 25% of the potential Japanese market may be the market at risk.

An examination of the buying patterns of countries revealed that in recent years Brazil has purchased its satellites from the Canadian manufacturer SPAR (which uses Hughes as a subcontractor) and the Arab States have purchased from the French company Aerospat (to which Ford is a subcontractor). Canada has recently purchased satellites [Anik-D] from the Canadian manufacturer, SPAR. In these cases it will be assumed that a country that is buying from a country that is developing the technology is not part of the market at risk, because it would be lost to U.S. manufacturers in any event. (Arabsat is an example) A country like Brazil that has been purchasing from a country not developing the technology is part of the market at risk, because

if the U.S. developed the technology, this part of the market might be captured. Finally, countries like Canada and the U.S. that are purchasing from their own manufacturers could be captured by foreign technology and therefore is considered part of the market at risk.

Areas that have consistently purchased from the U.S. and areas that had not committed to a contractor or shown trends towards buying from one particular country (Africa) in the Communications 21 study, were considered part of the market at risk.

Intelsat purchases satellites competitively. In the past three years U.S.manufacturers have represented about 80% of the value of Intelsat purchases and foreign subcontractors to U.S. companies about 20%. [9] Assuming that this trend would continue if the relative competitiveness of U.S. satellites to foreign manufactured satellites remained the same, the U.S. would risk losing the 80% of the uncommitted Intelsat market if foreign countries developed and produced the improved technology satellites and the U.S. didn't.

Table 7.7 presents a rough estimate of the size of the communication satellite market from 1990 through 2000 that could be lost to U.S. manufacturers, if U.S. technology does not remain competitive. The results are based on the Communications 21 study and the above assumptions. Indications are that the "at risk" market, i.e., the satellite market that is likely to gravitate with technology, is on the order of 4 to 5 billion dollars in the 1990 to 2000 time frame.

TABLE 7.7 AT RISK SATELLITE MARKET DURING THE 1990 - 2000 TIME PERIOD

COUNTRY/AGENCY	MARKET
Intelsat	$1392 Million
Asia	200 Million
Japan	115 Million
Latin America	290 Million
Africa	110 Million
Inmarsat	176 Million
U.S.	2,202 Million
Canada	277 Million
Total	$4,762 Million

8. OTHER APPLICATIONS OF METHODOLOGY

An objective of the reported effort was to develop an economic evaluation and planning capability appropriate for the evaluation of spacecraft technology programs such as space power and on-orbit propulsion systems. As described in previous sections of this report, the DOMSAT II Model is the cornerstone of this capability. The DOMSAT II Model is a stochastic financial simulation model that allows the impacts of S/C technology programs to be evaluated for a broad range of communication satellite business ventures providing a multiplicity of communications services. The Model simulates the performance of the business ventures explicitly and quantitatively taking into account uncertainty, unreliability and resulting risk.

The DOMSAT II Model provides the means for evaluating S/C technology programs and space transportation programs and related policies in terms of their impacts on the financial performance of communications satellite business ventures.

The ability to model the financial performance of communications satellite business scenarios together with the specification of typical business scenarios, provides the means for assessing the impacts of many public and private sector programs and policies. It is possible to analyze many related problems and issues with the assistance of the DOMSAT II Model. Possible analyses include the following:

* Assessment of the impacts of undertaking a broad range of S/C technology programs.

* Assessment of the impact of transportation system technology programs such as the development of low thrust upper stages for the transportation from LEO to GEO.

* Comparison of the financial consequences of utilizing alternative space transportation systems having different mission modes (i.e., expendable vs. reusable), reliability, accuracy of payload placement, price, etc.

* Assessment of transportation system pricing policies on specific business scenarios to provide insight into the likely consequences of transportation pricing policies on investment decisions.

* Assessment of the impact of cost of insurance and evaluation of the self-insurance alternative.

* Assessment of alternative S/C configurations, transponder arrangements and sparing concepts.

* Assessment of the potential market for upper stages (and associated pricing policy) in terms of the impact of the attributes of the stage on the financial performance of communications satellite business ventures.

All of the above may be accomplished directly by altering the input data set so as to reflect the technology attributes or policy issues of concern. For example, the effect of Space Shuttle pricing policy may be assessed by altering the transportation system price as a function of time. The financial impacts, assuming that transportation system price adjustments are not passed on to the consumer, can be observed by direct comparison of the financial performance measures with those of the base case scenario. The consequences of passing on the price adjustments to the consumers can be observed by adjusting transponder prices and including elasticity estimates.

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16. Abstract

Commercial organizations as well as government agencies invest in spacecraft (S/C) technology programs that are aimed at increasing the performance of communications satellites. The value of these programs must be measured in terms of their impacts on the financial performance of the business ventures that may ultimately utilize the communications satellites. An economic evaluation and planning capability has been developed and used to assess the impact of NASA on-orbit propulsion and space power programs on typical fixed satellite service (FSS) and direct broadcast service (DBS) communications satellite business ventures. Typical FSS and DBS spin and three-axis stabilized spacecraft were configured in the absence of NASA technology programs. These spacecraft were reconfigured taking into account the anticipated results of NASA specified on-orbit propulsion and space power programs. In general, the NASA technology programs resulted in spacecraft with increased capability. This report describes the developed methodology for assessing the value of spacecraft technology programs in terms of their impact on the financial performance of communication satellite business ventures. Results of the assessment of NASA specified on-orbit propulsion and space power technology programs are presented for typical FSS and DBS business ventures. This report consists of two volumes. Volume 1 describes the methodology and contains the results of the analyses performed for the on-orbit propulsion and space power technology programs. Volume 2 contains appendices describing the DOMSAT II Model and data base and includes user and programmer documentation.

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